

JUNE 1985 VOL. 7 NO. 6

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ROBOTICS

A G ETM

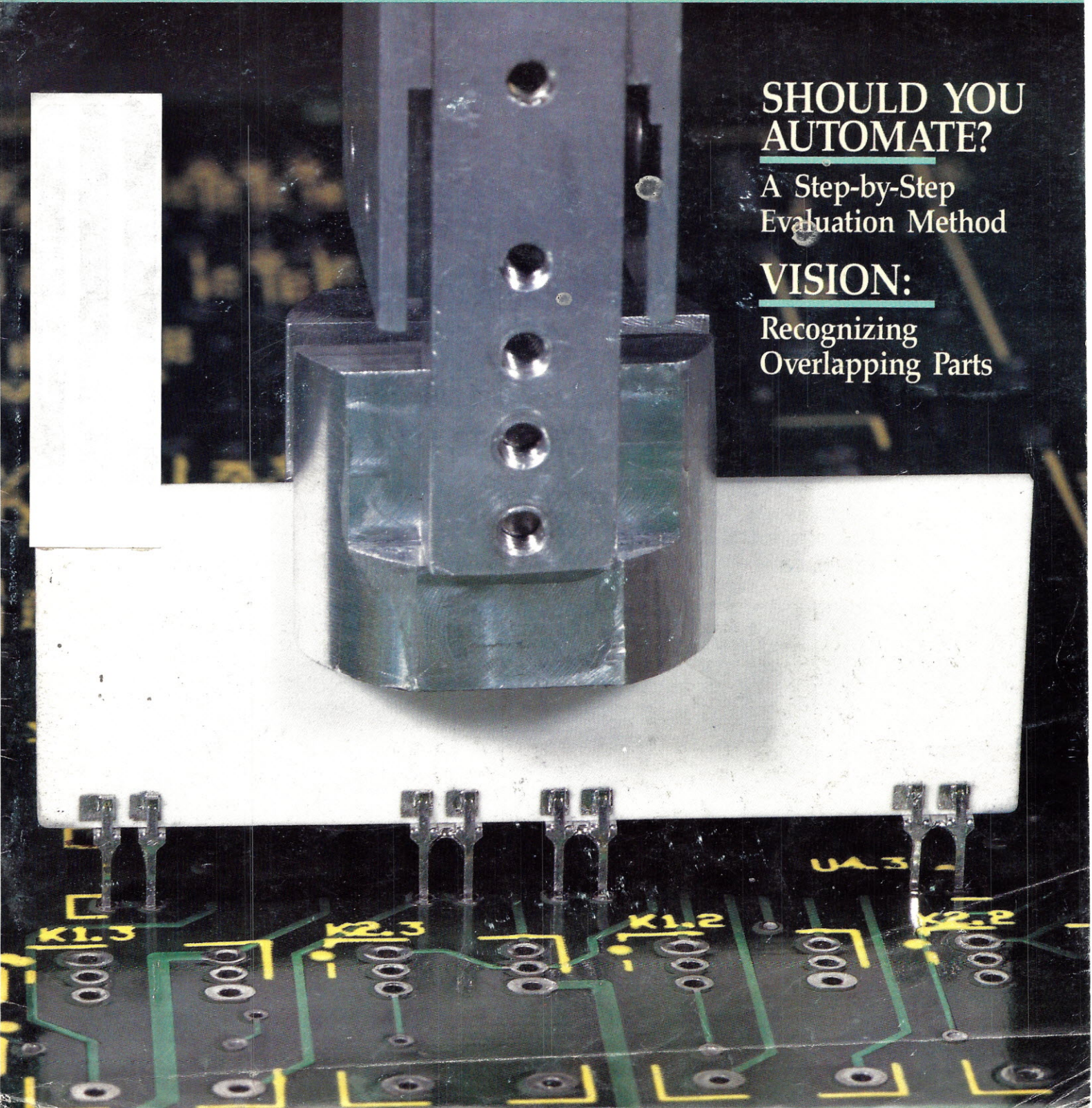
THE JOURNAL OF INTELLIGENT MACHINES

SHOULD YOU AUTOMATE?

A Step-by-Step
Evaluation Method

VISION:

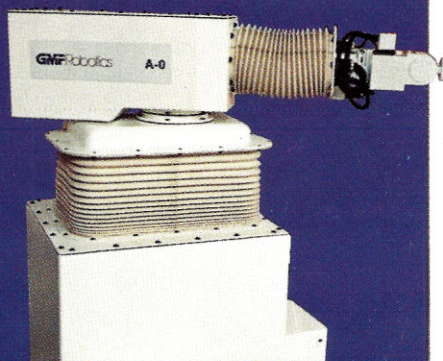
Recognizing
Overlapping Parts



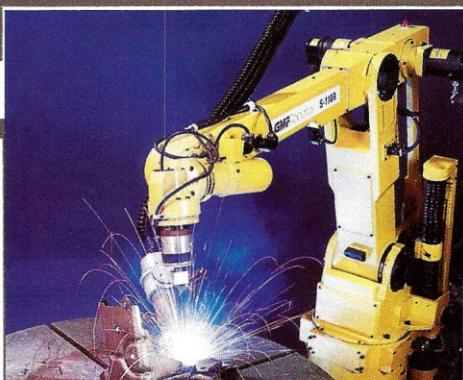
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ROBOTICS

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THE JOURNAL OF INTELLIGENT MACHINES

JUNE 1985

VOL. 7 NO. 6

EDITORIAL

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How Do I Get Where I'm Going? by Carl Helmers

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The decision to automate should not be based on monetary considerations alone. Decision theory is applied in a step-by-step approach to isolate and evaluate the factors essential to an informed choice.
- 17** A New Computerized Tomographic-Aided Robotic Stereotaxis System by Y. S. Kwoh, Ph.D., I. S. Reed, Ph.D., J. Y. Chen, M.Sc., H. M. Shao, Ph.D., and Edmond Jonckheere, Ph.D.
Experiments combining light industrial robots with computer tomographic scanners point the way to future high technology neurosurgical stereotactic procedures.

- 24** A Z80-Based, Multitasking Control System by Richard L. Weinbrenner
Software for simultaneous events in a real-time system is simplified by using multiple independent tasks. By separating fundamentally independent portions of a system's software, we achieve function while still allowing controlled interaction.

- 30** Recognizing Parts That Touch by Scott D. Roth
Discrete objects are relatively simple to recognize. But the situation becomes more complicated when a vision system is presented with a jumble of touching and overlapping parts.

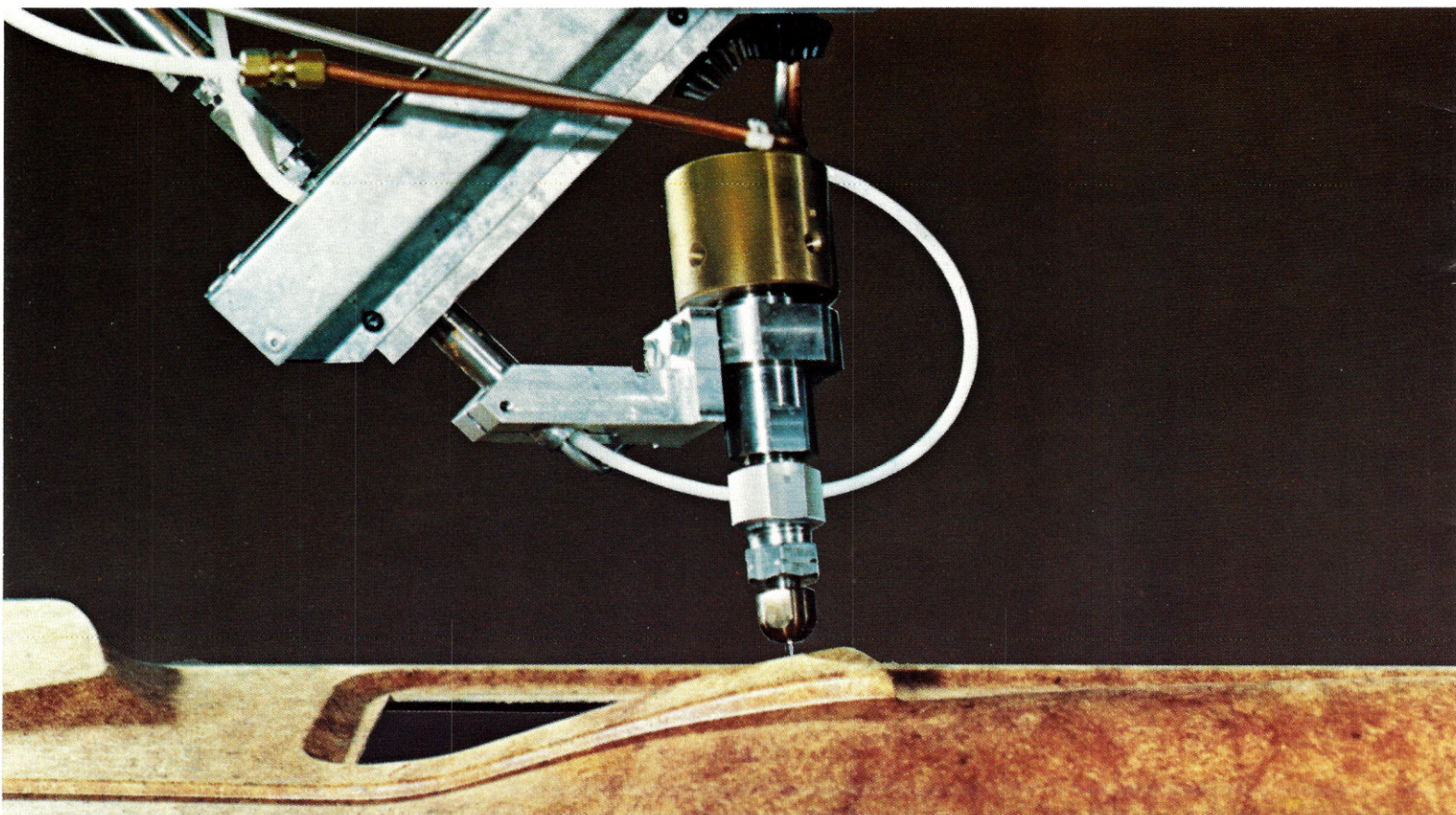
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About the cover: This month's cover, supplied by Adept Technology, Inc., shows the AdeptOne robot using AdeptVision to locate board circuitry and determine the location of leads on a high pin count integrated circuit.

Cut @ 25"/sec.



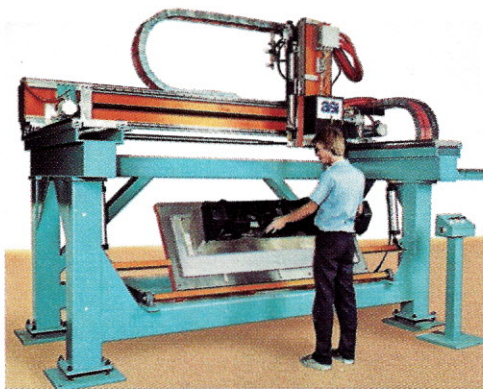
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Circle 1

Where Am I? How Do I Get Where I'm Going?

BY CARL HELMERS

This issue of *Robotics Age* is special. It is being shown off and distributed on the occasion of Robots 9, the ninth annual Robotics extravaganza of the Robotic Industries Association. The show this year returns to Detroit, a city whose name has long been synonymous with the automotive industry. So it is appropriate here to focus on one of the most interesting recent developments in robotics technology—a concept that promises to greatly update the automobile. This device, now in beta testing, is an aftermarket product concerned with optimum use of vehicles, as opposed to the automotive industry's already heavy application of robotics and computer-assisted manufacturing technology in the production of automobiles.

As we all know, many of the best aftermarket gadgets of past decades have become standard equipment in today's vehicles. Think of radios, air conditioners, trip computers, and a host of other devices in today's cars. This new product is perhaps the most sophisticated computer ever designed for installation in a road vehicle. It is a self-contained navigation computer that displays a detailed road map in color and in real time on a screen near the driver. This remarkable feat is achieved by a complete on-board database of a local portion of the road network, distance information from differential measurement of wheel rotation, and magnetic compass direction information. The dead reckoning feedback loop is closed by correlating the current estimated position with the database using a number of clever artificial intelligence pattern-matching techniques.

The database for a given region of the national road network is produced from a combination of census address data, satellite photographs, and other archival information massaged using sophisticated computer-aided preparation techniques. The database for the local region of travel is stored in compressed vector form on a high-speed, high-density modified Phillips style digital cassette. Using gobs of memory and processing power, most of the data for a given period of driving is referenced from memory, thus minimizing tape operations. The car computer uses its on-board database and sensors to keep track of current position, display the appropriate map on the screen, and optionally tie into the fleet operator's central computer via two-way radio. The result is an exceptionally useful product aimed at both the commercial market of fleet operators and individual business travellers who frequently make calls in unknown territory.

There have been earlier "concept car" attempts to make a navigation computer, but this one will probably be the first to be made commercially available. The manufacturer, Etak, Inc., is a high-technology startup company in Sunnyvale, California. Maps have been completed for approximately one fifth of North America, and the system is expected to be on the market this year.

Early fleet testing shows considerable economic incentive for having such a device. One model will cost about \$1500 for the basic machine, plus the price of the database tapes, but driving with Etak is expected to be some 15 percent more efficient in terms of miles spent getting to unfamiliar locations.

The Etak computer may well be an important stage in the development of the automobile automatic guided vehicle, the robot car. A navigation computer is not in itself a robot, but rather a vehicle system component. A car with a navigation computer is not a robot either—just an

extremely smart car. But if the on-board computer knows the car's location at all times, can the automatically driven car be far behind? When Etak begins delivery, the concept of an automobile navigation computer will begin to find acceptance.

The car, bus, or truck with a navigation computer will, to avoid trouble, still rely on the clear head, acute vision, and judgement of its driver. (Given all today's highway carnage, such a driver description might be a bit optimistic.) The car which can answer the question "Where am I?" will lead to the car which can intelligently respond to the request, "Would you take me to the store?" And the ultimate triumph of the entrepreneurial and experimental muses in engineering will be the car that can truly fly solo, with no human driver at all. ■

**See *Robotics Age* at Booth #763,
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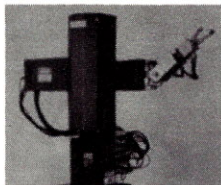
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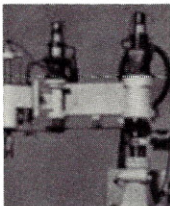
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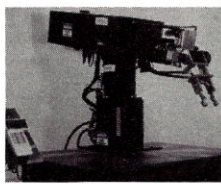
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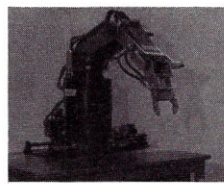
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Calendar

JUNE

3-5 June. 1985 Eastern Design Engineering Show and ASME Conference. Bayside Exposition Center, Boston, MA. Contact: Show Manager, Eastern Design Engineering Show, Cahners Exposition Group, 999 Summer St., Stamford, CT 06905, telephone (203) 964-8287.

Conference organizers describe the conference as "the first such East Coast event since such new technologies as CAD/CAM and composite materials have revolutionized the design engineering field." An outgrowth of the 32-year-old national show, the conference will have the same goals: the design of new products and the redesign of conventional products with concentration on improving the productivity of design engineers.

The design engineering division of the American Society of Mechanical Engineers will sponsor a program covering areas that have developed as the result of advances in computer technology, such as CAD/CAM, finite element analysis, composite materials development, and artificial intelligence and expert systems.

3-6 June. Robots 9. Cobo Hall, Detroit, MI. Contact: RI/SME Public Relations, One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-0777.

Almost everything that can be said and seen on the subject of robots will be offered at Robots 9 when 80 or more robotics experts discuss new breakthroughs in systems software, remote applications, vision, intelligent controls, management perspectives, and R&D. Other sessions will consider new developments in mechanical and electronic assembly, robot programming languages, safety, aerospace applications, human productivity implications, robot design, and justification and decision-making.

In addition, there will be an exhibition of more than 250 robots

and robotic systems demonstrating welding cells, laser processing, water-jet cutting, material handling, assembly, gantry applications, and other manufacturing operations. Many of the systems will be equipped with the latest vision and tactile sensors, new controls and positioning devices, and end effectors and tooling.

6-7 June. Workshop on Robot Standards. Ponchartrain Hotel, Detroit, MI. Contact: Leonard Haynes, A123 Metrology Building, NBS, Gaithersburg, MD 20899, telephone (301) 921-2181.

The National Bureau of Standards and the Navy's Computer-Integrated Manufacturing Technology Program will sponsor a workshop on robot standards in conjunction with the Robots 9 conference. Planned topics include control system interfaces to robots, sensors, databases, and high-level control systems; mechanical interfaces to grippers and other end effectors; programming languages and environments; measures of performance; and human interfaces.

The workshop is cosponsored by the Robotic Industries Association, the American Society for Testing and Materials, the Institute for Electrical and Electronic Engineers, the American National Standards Institute, and the Electronic Industries Association.

10-14 June. Robot Manipulators, Computer Vision, and Intelligent Robot Systems. The University of Stirling, Stirling, Scotland. Contact: Director of the Summer Session, Massachusetts Institute of Technology, Room E19-356, Cambridge, MA 02139, telephone (617) 253-2101.

The aim of this course will be to prepare the participant for the sophisticated methods soon to be employed in advanced automation. Emphasis will be placed on developing strategies for the solution of problems in sensing, spatial

Continued on page 6

15 Intelligent Ways to Master the Age of Robotics

Design for Assembly

M. M. Andreasen, S. Kühler, and T. Lund
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Machine Vision: The Eyes of Automation

J. Hollingum
1984, 113 pp., 38 illus., paper \$19.50
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Robotics — Planning and Implementation

C. Morgan
1984, 250 pp., cloth \$38.00
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The FMS Report

Ingersoll Engineers
Edited by J. Mortimer
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Thomas Müller
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A. Gomersall
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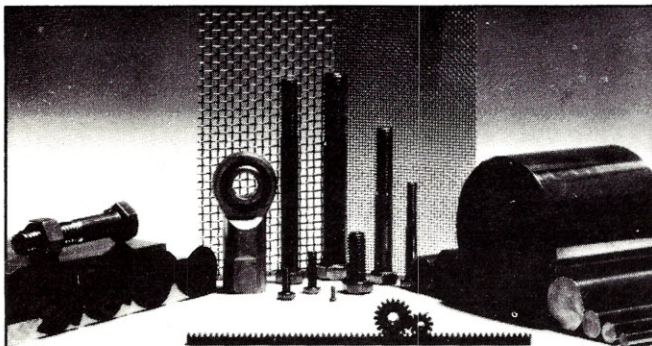
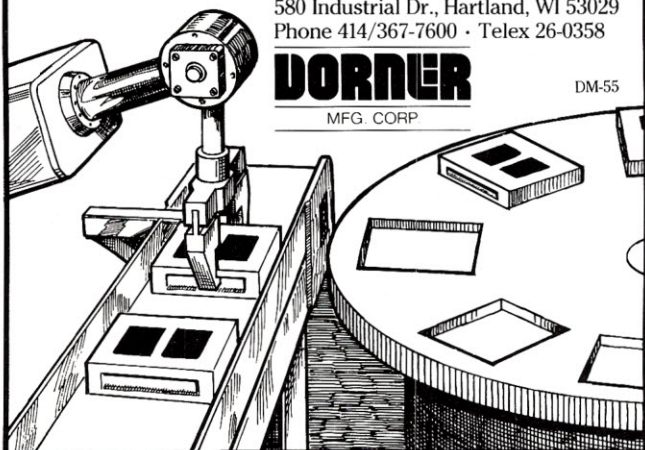
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Calendar

Continued from page 4

reasoning, and manipulation. The use of existing industrial robots and binary vision systems will be covered also.

11-13 June. Introduction to MAP and Related OSI Protocols. Hyatt Regency, Dearborn (Detroit), MI. Contact: Sally Davis, Senior Program Administrator, Special Programs Div., Society of Manufacturing Engineers, One SME Drive, PO Box 930, Dearborn, MI 48121, telephone (313) 271-1500, ext. 383.

The Computer and Automated Systems Association of the Society of Manufacturing Engineers will sponsor this workshop on the seven protocol layers of the MAP specification, including all currently specified protocols and those likely to be candidates for inclusion during 1985. Also to be covered are real time, cell architecture, application program interface to MAP, network layer interconnection, and recent advancements at the National Bureau of Standards.

12-14 and 17-19 June. Machine Vision in Manufacturing: A Hands-On Clinic. Los Angeles, CA. Contact: Joanne Rogers, SME Special Programs Dept., Society of Manufacturing Engineers, One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-0039.

Nello Zuech, president of Vision Systems International, will serve as chairman of this clinic, which will feature machine vision selection, implementation, and justification. Hands-on training will be offered on nine different machine vision systems. The sessions will also offer tutorials on machine vision functions and components.

12-15 June. 1985 Rochester Forth Conference. University of Rochester, Rochester, NY. Contact: Maria Gress, Institute for Applied Forth Research, Inc., 70 Elmwood Ave., Rochester, NY 14611, telephone (716) 235-0168.

The fifth Rochester Forth Conference is sponsored by the institute in cooperation with the Laboratory for Laser Energetics of

the university's college of engineering, the Rochester Section of the IEEE, and the Rochester Chapter of the IEEE Computer Society.

The focus will be on software management and engineering, and invited speakers will discuss Forth applications including real-time business, medical, space-based, laboratory and personal systems, and microchips. Also to be covered are Forth technology, including finite state machines, metacom-pilers, Forth implementation, control structures, and hybrid hardware/software systems.

18-20 June. Successful Implementation of Computer Integrated Manufacturing. Constellation Hotel, Toronto, Quebec, Canada. Contact: Sharilyn Shampine, Program Administrator, Special Programs Dept., Computer and Automated Systems Association of Society of Manufacturing Engineers, One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-1500.

The program of this conference will cover components of a CIM system; methods of integration, planning, and managing for CIM; and development projects underway. There will be a roundtable session in which conferees will be able to discuss individual questions with the speakers.

24-27 June. Fourth International Symposium on Unmanned Untethered Submersible Technology. University of New Hampshire, Durham, NH. Contact: Carol Bryant, University of New Hampshire, Marine Systems Engineering Laboratory, PO Box G, Durham, NH 03824, telephone (603) 749-6056.

This symposium will cover subjects such as acoustics/communications, imaging, control dynamics, artificial intelligence, data sources/sinks, and knowledge-based guidance. The emphasis will be on stimulating informal interaction among the participants. A one-day classified session is also planned.

Calendar

24-28 June. Robotics: Concepts, Theory, and Applications. University of Michigan, Ann Arbor, MI. Contact: Engineering Summer Conferences, 200 Chrysler Center, North Campus, the University of Michigan, Ann Arbor, MI 48109, telephone (313) 764-8490.

Concepts and mathematics of computer-based robots will be addressed in sessions focusing on kinematics; dynamics; control; robotic vision, sensing, and control; robotic languages; economic justification; and applications. There will also be laboratory sessions on PUMA robot arms.

24-28 June. Prolog Programming Workshop. Structured Methods, Inc., New York, NY. Contact: Keith Eisenstark, Structured Methods, Inc., 7 West 18th St., New York, NY 10011, telephone (212) 741-7720 or (800) 221-8274.

The first half of this course will cover the basics of the language and the second half will be devoted to applications, including parsing, natural language processing, query languages, knowledge representation formalisms, and programs for expert consultation. Visible Prolog will be used to acquaint participants with the Prolog execution model. Exercises will involve program writing and creation of a system for expert consultation.

27-28 June. First Annual Workshop on Robotics and Expert Systems. Johnson Space Center, NASA, Houston, TX. Contact: Dr. Fred King, Registration Chairman, Ford Aerospace/M4B, PO Box 58487, Houston, TX 77258, telephone (713) 280-6868.

The workshop, cosponsored by the Robotics and Experts Systems Group and ISA Clear Lake Galveston Section, will feature technical papers on expert systems, industrial robotics, computer algebra, AI for man/machine communications, teleoperations and space robotics, sensors and vision, distributed AI, and automated programming. There will also be tutorials on expert systems and industrial automation.

JULY

8-12 July. Robot Manipulators, Computer Vision, and Automated Assembly. Massachusetts Institute of Technology, Cambridge, MA. Contact: Director of the Summer Session, Room E19-356, Massachusetts Institute of Technology, Cambridge, MA 02139, telephone (617) 253-5863.

This short course in industrial robotics is being offered under the auspices of MIT's Artificial Intelligence Laboratory. The 57 topics to be covered fall under the general headings of robot manipulators, computer vision, automated assembly, applications, and systems components. The emphasis of the course will be on developing strategies for the solution of problems in sensing, spatial reasoning, and manipulation.

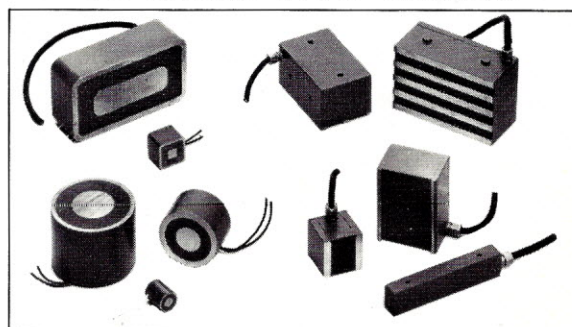
15-17 July. 12th Annual Symposium of the Association for Unmanned Vehicle Systems. Anaheim Marriott Hotel, Anaheim, CA. Contact: John Ganoe, AUVS Executive Director, 1133 Fifteenth St. N.W., Washington, DC 20005, telephone (202) 429-9440.

The symposium will address such topics as applications and operations, cost effectiveness, vehicle and systems, avionics and navigation, command and control/programming, sensors and payloads, and robotics and AI. There will also be an exhibit.

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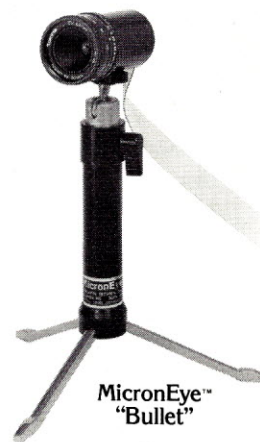
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JUSTIFYING THE ROBOTICS REPLACEMENT DECISION

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and

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Arizona State University
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It is difficult to justify investments in robots purely on monetary grounds. Other strategic and nonmonetary factors have to be considered. Many important choice factors confront the decision maker when resolving the trade-off between objectives. Sometimes factors such as health hazards, national interest, and fear of no longer being competitive may override any immediate economic consideration. (For examples, see Agee, Hutchinson, and Sanders.) These noneconomic and subjective factors are virtually impossible to equate with a monetary value. Teitz states, "To analyze systems of facilities with static equilibrium analysis is to ignore a most important characteristic—their changes over time." Some of the nonquantifiable factors to which dollar value cannot be assigned may have hidden benefits that might not be readily evaluated at present but may prove to have substantial benefits in the future.

Other benefits such as improved productivity reflect immediately on implementation but are difficult to assign a dollar value to. These hidden long-term and immediate nonquantifiable benefits, along with the financial factors, need to be combined in the evaluation process to justify investments in robots.

Multicriteria decision problems have been increasingly interesting management scientists, particularly problems that are strategic in nature as observed by Soland.

Engineering decision analysis studies today basically concern cost-reduction aspects rather than revenue-creation aspects and operate mainly within the tactical level of decision making rather than strategic investment. Due to this narrow approach and interpretation concerning low-level decision-making, engineering analysis has been criticized. With the increased use of technology, replacement analysis demands decision makers to be involved with revenue creation and long-term strategic outlook.

The essence of utility theory is to provide a function, a utility function, which transforms payoffs (both quantitative and qualitative) into a utility scale, usually 0–100. The multiattribute model SMART (simple multiattribute rating technique) was used in our work. This technique is usually called the Multi-Attribute Utility Measurement (MAUM). It has emerged in recent years to meet the requirement of multicriteria decision-making (Fleischer). It considers both quantitative impacts (costs and reliability) and qualitative impacts (immediate and long-range benefits that cannot be quantified). The model is developed in this article by means of a simple example to evaluate the alternative of using a robot as opposed to a human performing the same job.

In various utility models, the preferences of a decision maker are used to evaluate the alternatives under review. The salient

feature of the SMART approach is that it takes the analysis an additional step, since it

- involves the decision makers in determining the attributes,
- allows decisions to be taken based on consensus, and
- permits discussion of differences in point of view on how to assign overall worth to alternatives.

The implementation of the SMART modelling technique and its operation can be explained briefly in ten steps with a simple example outlining the procedures involved. The process as involved in outcome evaluation is shown in Figure 1.

Step 1: Identify the person or organization whose desires (utilities) are to be maximized. Often several individuals and groups have stakes and voices in the decision; they must all be identified. In the example of robot evaluation, higher management, production workers, and middle management may be identified as decision makers since the robotic application involves total integration and the utility of each group has to be maximized.

Step 2: Identify the issue or issues (that is, decisions) to which the utilities needed are relevant. This step clarifies the nature of the decision to be made. For example, if a car is to be purchased, it is essential to specify whether it should be a family car, a car to race, etc. Each use tends to bring different sets of values to mind. For robotic

BLOCK DIAGRAM OF AN OUTCOME EVALUATOR

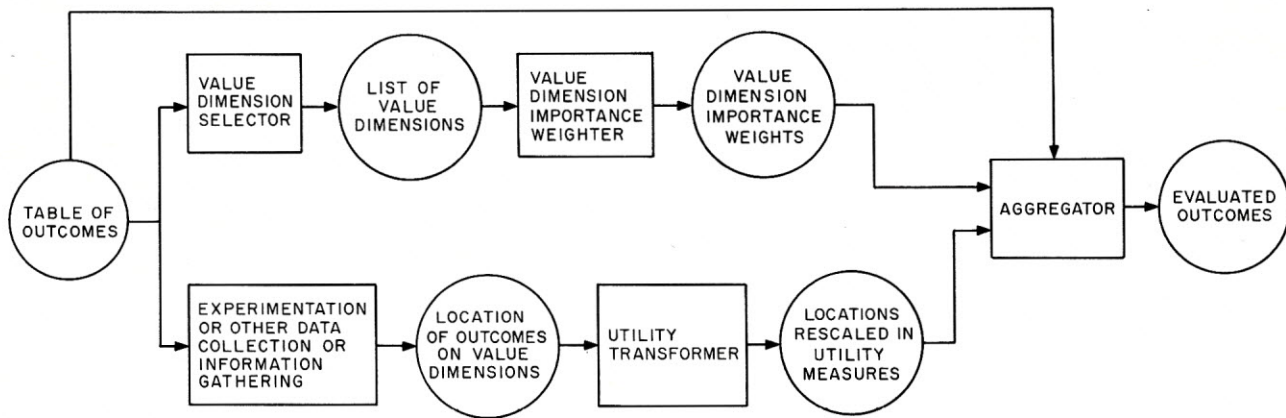


Figure 1. Block Diagram of an Outcome Evaluation. The SMART modelling technique discussed in text involves two parallel paths of evaluation, as shown here. Starting with a table of outcomes, the upper path involves weighting the various factors of a decision. The lower path of the model concerns determination of "utility" measures. The evaluated outcomes are determined by combining weight and utility measures with the original input of a table of outcomes.

evaluation productivity improvement, consistency in quality or a hazardous job environment may be considered.

Step 3: Identify the entities to be evaluated. In this step, the different alternatives are identified. The application of robots challenges and competes with manual labor. The alternatives in this example are robots and manual labor. In SMART, value models can be developed before any alternatives are developed. After the evaluation model has been developed, additional alternatives can be proposed for consideration without necessitating a revision of the value model.

Step 4: Identify the relevant dimensions of value. In the first three steps, more or less philosophical questions like "Whose utility?", "Utility for what purpose?", and "Utility of what entities?" were answered. In this step, the first technical question is encountered, namely what dimension of value (i.e., what attribute or scales of effectiveness) is important in helping to choose among alternatives. Table 1 lists some attributes, which many experts cite as important in the robot evaluation example presented in this article. As a general rule, 15 attributes can be considered ample, but some analyses may demand more. When the weighting process is completed (which will be done in steps 6, 7, 8), the decision tends almost exclusively to be a function of the top five or six attributes. However, when multiple decision makers are involved, as in the robotic evaluation, low-ranking attributes for one interest group may be highly important for another group. Hence, identifying as many at-

tributes as may be deemed important by various groups should be considered in robotic evaluation.

Step 5: Rank the dimensions in order of importance. Ranking can be performed either by an individual, by representatives of conflicting values acting separately, or by those representatives acting as a group. In this step, value differences begin to show up. For robotic evaluation groups, ranking is suggested to force a consensus to resolve individuals' differing preferences and value

systems. Table 1 shows a sample ranking for robotic evaluation. In this step, Nominal Group Technique (NGT) may be adopted to reach consensus on ranking of attributes (refer to Sink for details of its application).

Step 6: Rate dimensions in importance, preserving ratios. This can be performed by assigning the least important dimension an importance of 10 (10 is used rather than 1 to permit subsequent judgments to be finely graded and nevertheless made in integers). The next least important dimen-

TABLE 1
Weighting the Attribute

Rank (1)	Attribute Name (2)	Weighted Ranking (3)	Percent Total (4)
1	Healthy business	4500.00	17.50%
2	Available funding	4200.00	16.33%
3	Purchase & installation cost	3500.00	13.61%
4	Management/technical know how	3000.00	11.66%
5	Management commitment	2000.00	7.78%
6	Attitude toward risk	2000.00	7.78%
7	Cost saving	1700.00	6.61%
8	Operating cost	1000.00	3.89%
9	Hazardous environment	900.00	3.50%
10	Educational & training cost	700.00	2.72%
11	Flexibility	600.00	2.33%
12	Repetitive motions	500.00	1.94%
13	Shop management support	410.00	1.59%
14	Labor support	400.00	1.56%
15	Return on investment	160.00	0.62%
16	Operating simplicity	80.00	0.31%
17	Tax benefits/depreciation	40.00	0.16%
18	Strenuous task	20.00	0.08%
19	Tedious, boring task	10.00	0.04%
Grand Total		25720.00	100.00

Note: The units of the weighted ranking are arbitrary. The relationships between percent totals are the deciding factors.

sion is then assigned a number that reflects a ratio compared to the least important ratio, and so on. As an example, Table 1 shows weighted ranking in column three. It is evident from the table that there is no upper limit on weights, and if the list of attributes is large, the most important attribute might have a weight many times larger than the weight of the least important attribute. Decision makers should change weights until they feel that the weights accurately reflect their preferences.

Step 7: Normalize the weights by taking the sum of all weights, dividing each attribute's weight by the sum, and multiplying by 100. This converts importance weights into numbers that, mathematically, are like probabilities. The choice of a 0 to a 100 scale is purely arbitrary. Column four of Table 1 shows the results of the computation involved in this step.

Step 8: Measure the location of each entity being evaluated on each dimension. In this step, value curves for each dimension are constructed. Participants in the decision-making process are asked to draw their utility graph for the appropriate dimensions. The horizontal axis of each group represents the plausible range of levels of effective performance for the attribute under consideration. The vertical axis represents the range of values, or scores, associated with the corresponding levels of performance recorded on horizontal axis. The value curves translate each alternative performance from its natural scale to a scale that presents the value of that performance. Sample utility graphs as applicable to the robotic example presented here are shown in Figure 2; the curves show the utility of a decision maker who sets up preference in low, medium, and high ranges, thereby expressing his preference in a plausible range instead of providing a single value curve, which is difficult to ascertain.

Step 9: Calculate utilities for entities. The following equation may be used to calculate utilities:

$$U_i = \sum_j W_j U_{ij}$$

where U_i = total weighted score for alternative i , W_j = importance weight of the j th attribute, or dimension, U_{ij} = unweighted score for the i th entity on the j th attribute, W_j is the output of Step 7, and U_{ij} is the output of Step 8. The above equation is nothing more than the formula

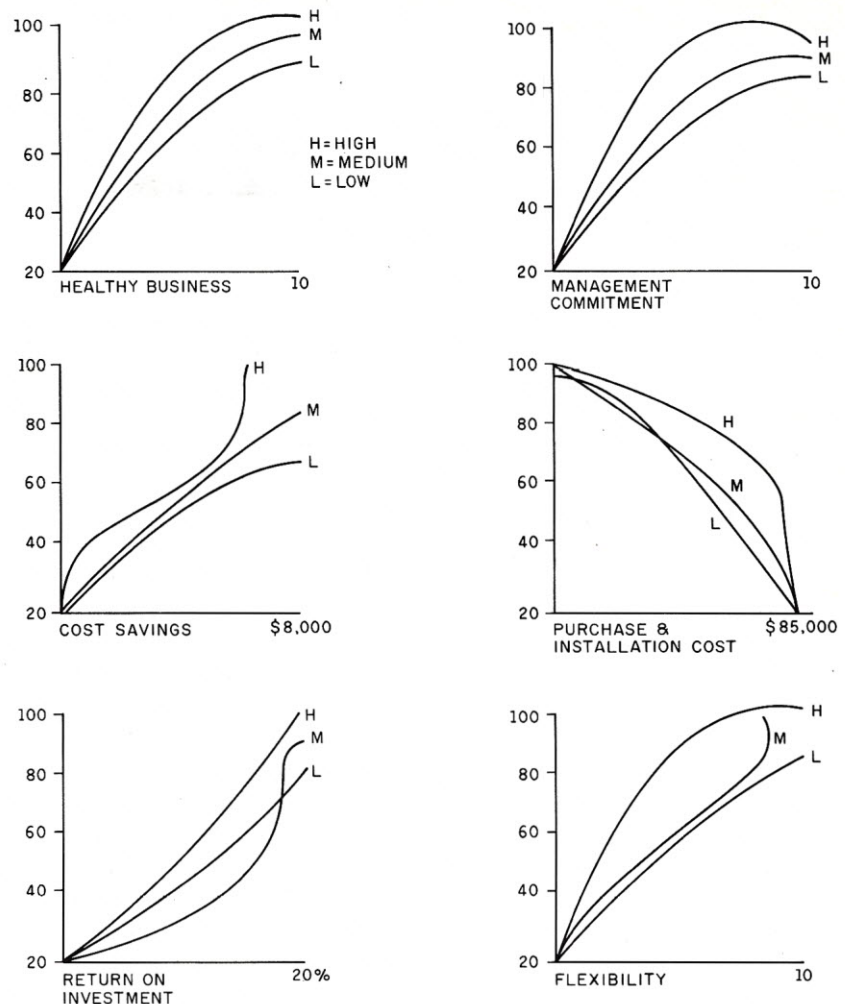


Figure 2. Six sample utility graphs from the Integrated Computer Aided Manufacturing (ICAM) project study by Huang and Ghanforoush. For each factor, low, medium, and high range curves of relative utility (0 to 100) versus the factor's quantifiable dimensions are generated.

for a weighted average. A word of caution on the weighting technique has to be mentioned here. As commented by Hobbs, "Users of weighting summation sometimes are unaware of the stringent conditions necessary for the models used, to be consistent with underlying assumptions." The most important condition is that the weights are to be proportional to the relative value of unit changes in their attribute value function. Some concern over judgments of individual participants, which would be combined into a single judgment utility curve in the next step, may arise. Hannon has suggested a statistical measure of compatibility of judgment, the coefficient of concordance, which is based on rank order. We suggest sensitivity analysis as a means to help decision makers to decide their true preference. Sensitivity analysis is performed by analyzing the low, medium, and high range of the decision

maker so he can see graphically the effect of his choice preference in the plausible range and reflect his true single value preference based on the analysis.

Table 2 shows the data matrix, displaying the level of performance for each alternative and its attributes. The unweighted scores for the example are summarized in Table 3. The individual scores for each alternative-attribute pair are determined by reading from the value curves of Figure 2 at the point of the attribute value in Table 2. Table 4 summarizes the scores after they have been multiplied by their respective importance weight. The grand total represents the overall value, or score, of the alternatives, namely: a) using robot, b) job performed manually, for the low, medium, or high range.

Step 10: In this step a decision is made by rank ordering the alternatives evaluated by the overall values determined in Step

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TABLE 2
Empirical Data Matrix

Rank	Attribute Name	Alternatives	
		Robot	Manual
1	Healthy business*	9.00	6.00
2	Available funding*	8.00	7.00
3	Purchase & installation cost	\$72,000.00	\$ 1,500.00
4	Management/technical know how*	7.50	2.50
5	Management commitment*	8.60	5.00
6	Attitude toward risk*	2.50	8.60
7	Cost saving	\$ 5,600.00	\$ 3,450.00
8	Operating cost	\$ 5,200.00	\$20,000.00
9	Hazardous environment*	8.60	2.00
10	Educational & training cost	\$ 4,500.00	\$ 500.00
11	Flexibility*	5.00	9.00
12	Repetitive motions*	8.00	5.00
13	Shop management support*	6.00	9.00
14	Labor support*	6.00	9.00
15	Return on investment	11.30%	15.00%
16	Operating simplicity*	7.00	9.00
17	Tax benefits/depreciation	\$ 8,000.00	\$ 500.00
18	Strenuous task*	9.00	5.00
19	Tedious, boring task*	7.50	2.50

*Units from 10 point scale, from 0 (worst) to 10 (best).

Note: Each factor is evaluated in either subjective (0-10) or numerical units such as dollars or percentages with respect to the various alternatives. The SMART technique uses this data to formally evaluate the alternatives.

Column four in Table 1 is calculated by taking the percentage of total weighted ranking. Table 3 is tabulated by plugging the Data Matrix value from Table 2 in the value curves of the decision maker. The low, medium, and high unweighted scores for manual vs. robot operation are weighted by multiplying with the weight factor calculated in column four of Table 1. The weighted score for each attribute is summed up for the alternatives, namely robot and manual, and the decision is based on the overall highest score. The sensitivity of the decision makers' choice preference in the low, medium, and high range is projected graphically to study the effect on decision-making. Subjective (SFM) and objective (OFM) factor measures are totaled separately as shown in Table 5. The performance measure (PM) can be determined by noting that:

$$PM = OFM \cdot X + (1 - X) \cdot SFM$$

where X is the fraction of decision weight based on quantifiable monetary values.

TABLE 3
Summary of Unweighted Scores

Rank	Attribute Name	Robot			Manual		
		Low	Medium	High	Low	Medium	High
1	Healthy business	55.0	78.0	90.0	52.0	58.0	72.0
2	Available funding	74.8	89.0	95.0	78.0	82.0	90.0
3	Purchase & installation cost	36.0	48.0	55.0	75.0	88.0	96.0
4	Management/technical know how	65.5	86.3	91.5	28.3	38.9	48.3
5	Management commitment	78.3	89.9	98.5	60.1	69.8	72.9
6	Attitude toward risk	18.0	26.0	30.0	73.2	85.0	91.0
7	Cost saving	78.0	92.0	95.0	73.2	76.5	88.0
8	Operating cost	86.4	95.3	98.6	46.5	47.2	48.5
9	Hazardous environment	90.0	96.0	99.0	23.0	31.5	35.0
10	Educational & training cost	74.2	81.3	86.5	70.2	89.4	93.1
11	Flexibility	69.3	78.7	85.0	79.2	88.2	91.2
12	Repetitive motions	89.4	90.1	93.5	72.1	79.3	86.0
13	Shop management support	76.4	79.5	81.3	85.3	89.2	91.3
14	Labor support	50.1	68.5	75.4	88.3	92.4	96.0
15	Return on investment	63.5	78.6	90.5	73.8	88.6	98.6
16	Operating simplicity	46.8	70.8	86.4	58.2	73.5	98.1
17	Tax benefits/depreciation	89.3	92.8	98.5	48.2	53.5	60.3
18	Strenuous task	74.2	88.3	93.8	30.9	58.3	70.3
19	Tedious, boring task	78.5	83.6	89.5	20.1	35.2	46.3

9. More than one set of rank orderings will be available for inspection when multiple participants are involved in the decision-making process. Based on the consensus of the decision makers, a combined single utility curve could be calculated in Step 9 itself, within certain acceptable deviation

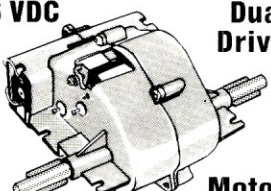
limits as discussed in Step 9. However, it is suggested that the value difference evaluated by different decision makers be carried individually until this step, so that sources of disagreement can be identified and sorted out with common consensus of all the decision makers.

Therefore,

$$\begin{aligned} PM \text{ (Robot low)} &= 15.97X + (1 - X)45.69 \\ PM \text{ (Robot medium)} &= 19.17X + (1 - X) 56.84 \\ PM \text{ (Robot high)} &= 20.67X + (1 - X) 62.04 \end{aligned}$$

TABLE 4
Summary of Weighted Scores

Rank	Attribute Name	Weight Factor	Robot			Manual		
			Low	Medium	High	Low	Medium	High
1	Healthy business	0.1750	9.63	13.63	15.75	9.10	10.15	12.60
2	Available funding	0.1633	12.21	14.53	15.51	12.74	13.39	14.70
3	Purchase & installation cost	0.1360	4.90	6.53	7.48	10.20	11.97	13.06
4	Management/technical know how	0.1166	7.64	10.06	10.67	3.30	4.54	5.63
5	Management commitment	0.0778	6.09	6.99	7.66	4.68	5.43	5.67
6	Attitude toward risk	0.0778	1.40	2.02	2.33	5.69	6.61	7.08
7	Cost saving	0.0661	5.16	6.08	6.28	4.84	5.06	5.82
8	Operating cost	0.0389	3.36	3.71	3.84	1.81	1.84	1.89
9	Hazardous environment	0.0350	3.15	3.36	3.47	0.81	1.10	1.23
10	Educational & training cost	0.0272	2.02	2.21	2.35	1.91	2.43	2.53
11	Flexibility	0.0233	1.61	1.83	1.98	1.85	2.06	2.12
12	Repetitive motions	0.0194	1.73	1.75	1.81	1.40	1.54	1.67
13	Shop management support	0.0159	1.21	1.26	1.29	1.36	1.42	1.45
14	Labor support	0.0156	0.78	1.07	1.18	1.38	1.44	1.50
15	Return on investment	0.0062	0.39	0.49	0.56	0.46	0.55	0.61
16	Operating simplicity	0.0031	0.15	0.22	0.27	0.18	0.23	0.30
17	Tax benefits/depreciation	0.0016	0.14	0.15	0.16	0.08	0.09	0.10
18	Strenuous task	0.0008	0.06	0.07	0.08	0.02	0.05	0.06
19	Tedious, boring task	0.0004	0.03	0.03	0.04	0.01	0.01	0.02
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TABLE 5
Subjective/Objective Factor Total

Attribute Name	Robot			Manual		
	Low	Medium	High	Low	Medium	High
Healthy business*	9.63	13.65	15.75	9.10	10.15	12.60
Available funding*	12.21	14.53	15.51	12.74	13.39	14.70
Management/technical know how*	7.64	10.06	10.67	3.30	4.54	5.63
Management commitment*	6.09	6.99	7.66	4.68	5.43	5.67
Attitude toward risk*	1.40	2.02	2.33	5.69	6.61	7.08
Hazardous environment*	3.15	3.36	3.47	0.81	1.10	1.23
Flexibility*	1.61	1.83	1.98	1.85	2.06	2.12
Repetitive motions*	1.73	1.75	1.81	1.40	1.54	1.67
Shop management support*	1.21	1.26	1.29	1.36	1.42	1.45
Labor support*	0.78	1.07	1.18	1.38	1.44	1.50
Operating simplicity*	0.15	0.22	0.27	0.18	0.23	0.30
Strenuous task*	0.06	0.07	0.08	0.02	0.05	0.06
Tedious, boring task*	0.03	0.03	0.04	0.01	0.01	0.02
Subjective factor total	45.69	56.84	62.04	42.52	47.97	54.03
Purchase & installation cost	4.90	6.53	7.48	10.20	11.97	13.06
Cost saving	5.16	6.08	6.28	4.84	5.06	5.82
Operating cost	3.36	3.71	3.84	1.81	1.84	1.89
Educational & training cost	2.02	2.21	2.35	1.91	2.43	2.53
Return on investment	0.39	0.49	0.56	0.46	0.55	0.61
Tax benefits/depreciation	0.14	0.15	0.16	0.08	0.09	0.10
Objective factor total	15.97	19.17	20.67	19.30	21.94	24.01

$$\begin{aligned} \text{PM (Manual low)} &= 19.30X + (1 - X) 42.52 \\ \text{PM (Manual medium)} &= 21.94X + (1 - X) 47.97 \\ \text{PF (Manual high)} &= 24.01X + (1 - X) 54.03 \end{aligned}$$

The six linear equations are plotted in Figure 3. Note that the manual operation is preferred for $0 \leq X \leq 0.58$ in the low range of scores. For the high range of scores for $X > 0.3$, robot is preferred to manual operation. For medium range, robot application is clearly preferable to manual operation. As interesting insights, note that when medium-range robot score, and high-range manual scores are considered, the manual operation dominates for $0 \leq X \leq 0.65$. Depending upon the preference demand deemed important by the decision maker, the objective factor (quantifiable monetary) or subjective factor may be given more weight.

The dilemma of the robot acquisition or replacement decision is clearly demonstrated. If only quantitative factors are used (a low X in the model), then the decision is for manual labor. If, on the other hand, the qualitative factors are included (high X), then the robot is preferred. Table 5

summarizes the data for our example. Subjective factors outweigh objective factors roughly three to one regardless of the high, medium, or low range of manager utility used. In such a situation, the bottom line is that shown by the grand total in Table 4—namely, robots are a better choice.

The SMART technique offers an excellent means to evaluate alternatives when monetary and nonmonetary attributes are to be considered and when the decision is to be based on consensus. Using SMART, the problem of participants with a strong bias toward a particular alternative is reduced, since in developing the importance weights, participants make a trade-off among different types of impacts (observed level of performance). SMART does not permit one or two impacts to become so dominant that they aggravate existing sources of conflicts and disagreement and overshadow group processes that might otherwise produce overall agreement. Considering the salient features of SMART, we feel that the model is appropriate for evaluating replacement analyses that are strategic in nature and where nonquantifiable factors play an important role in the long-term benefits.

The SMART evaluation model is different from the traditional evaluation techniques, which deal with benefit cost ratios, payback, or present worth criteria. These models are based on the assumption that all factors can be quantified in terms of money. SMART provides a new technique to evaluate high-technology capital equipment and also considers non-quantifiable factors in its evaluation procedure.

Some data for the robot example (Table 2, Data Matrix) was assumed. The key attributes in the evaluation process were collected from the ICAM (Integrated Computer Aided Manufacturing) project study by Huang and Ghandforoush.

Some objections raised in use of MAUM models are as follows:

- Human value judgments are based on a large number of complex considerations. No mathematical model can ever capture all of these considerations.
- People are not machines calculating values according to simple arithmetic rules. Therefore, the models must be wrong.
- Even if human preferences can, in principle, be represented by algebraic

models, the additive, quasiadditive, and multilinear models are too simplistic to reflect the subtle ways in which human beings combine value considerations in arriving at an overall value judgment.

- It is totally problem specific, and the results cannot be generalized to other problems.
- The preferences of one person are quantified, so that the applicability of the results rests on how well that person understands both the relevant facts and the values of the group(s) he represents.
- It is a time-consuming and expensive process that may require the service of a trained decision analyst and provides no guarantee of a clear, numerical solution at the end.

Some of these arguments are emotional in nature, but others are well-formulated. The strongest counterargument to these criticisms is that the method, in practice, is simple, easy, and reliable to use. In fact, two studies have been reported by Fischer on recent developments in multiattribute

utility theory. He finds that the traditional statistical approach assumes that a decision maker can make a relatively large number of utility assessments, each of

which may include a random error component. The explicit utility decomposition methods, by contrast, assume that the decision maker need make only a small

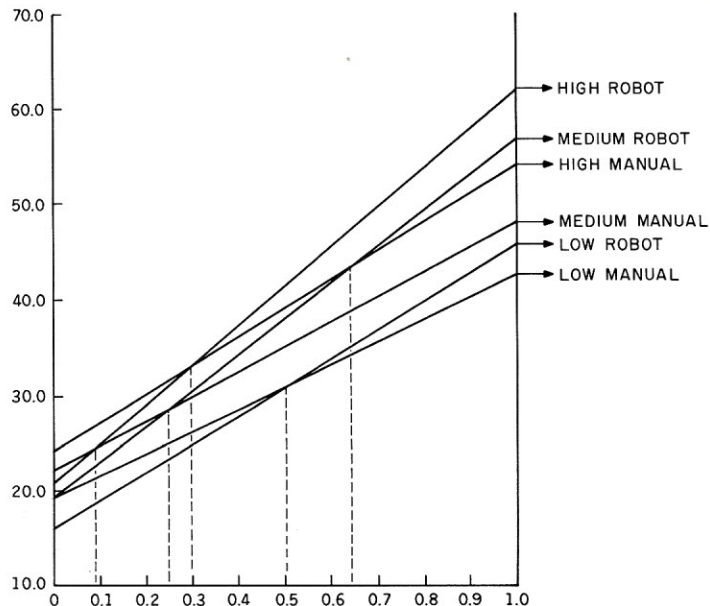
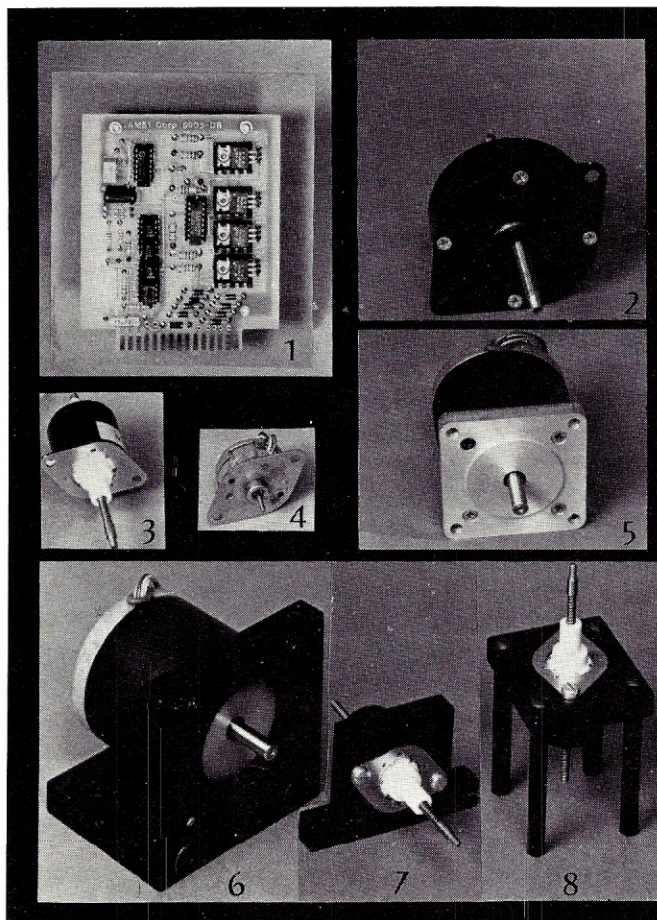


Figure 3. The set of linear equations giving performance measure versus the fraction of the weighted score due to objective factors yields this set of graphs in the example. The vertical dotted lines show various decision or crossover points.



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assessments.

Final conclusions in support of MAUM
by Fisher and Bandy are listed below.

- Simple algebraic MAUM models provide excellent approximations to human preferences in virtually every context studied by psychologists.
- Both statistical and direct decomposition approaches to MAUM modeling seem capable of providing valid representations of human preferences.
- If risk is an important role in decision problems, then use of lottery-based procedures is suggested as superior to the rating-scale method, though little experimental evidence is available to suggest that people can use lottery-based procedures in a meaningful way.

SMART is superior to approaches that involve artificially valuing all considerations in terms of one variable. The model encourages decision makers to think comprehensively and systematically about all the aspects of their problem, the way they naturally do.

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Step 1

Identify the person or organization whose desires are to be maximized.

Step 2

Identify the issue or issues to which the utilities needed are relevant.

Step 3

Identify the entities to be evaluated.

Step 4

Identify the relevant dimensions of value.

Step 5

Rank the dimensions in order of importance.

Step 6

Rate dimensions in importance, preserving ratios.

Step 7

Normalize the weights by taking the sum of all weights, dividing each attribute's weight by the sum, and multiplying by 100.

Step 8

Measure the location of each entity being evaluated on each dimension.

Step 9

Calculate utilities for entities.

Step 10

Make a decision by rank ordering the alternatives evaluated by the overall values determined in Step 9.

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A NEW COMPUTERIZED TOMOGRAPHIC-AIDED ROBOTIC STEREOTAXIS SYSTEM

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Stereotactic neurosurgery is a technique for guiding the tip of a probe or other delicate instrument to a predetermined point in the nervous system without direct viewing of the surgical site. Referencing is provided by a stereotactic head frame, a brace into which the patient's head is placed. Reference marks along two axes are used to locate and position surgical instruments. To visualize the interior of the skull, a computerized tomography (CT) scan is used, providing two-dimensional, high-resolution, axial pictures that show detailed soft-tissue anatomy inside the cranial vault and the spinal cord.

Use of the stereotactic head frame presents the surgeon with certain problems: the manual adjustments required by the frame are time-consuming, making frequent trajectory modifications difficult. The physical difficulties of reading the CT scan data and setting appropriate parameters on the frame could lead to human errors. Finally, a frame between surgeon and patient can be an awkward arrangement.

This article concerns the development of surgical procedures using a robot arm programmed to replace the stereotactic

frame. Driven by a computer, the arm offers substantial flexibility, speed, and accuracy, allowing the surgeon to conveniently manipulate the probe trajectory in a variety of directions. The result is expected to be increasingly sophisticated stereotactic procedures.

Stereotaxis is a technique that has been developed and used for almost 80 years. Horsley and Clarke first invented the 3-D stereotactic machine [1,2]. Since this pioneering effort, many stereotactic equipments have been devised [3-5]. In the early stereotactic surgeries, the road map to the target was provided by conventional x-ray pictures that were often enhanced by contrast material techniques.

In the late 1970s, the integration of stereotaxis with computerized tomographic scanning provided a much more powerful tool for surgeons. The new technique uses high-resolution axial two-dimensional pictures to guide the probe to the target with unsurpassed accuracy. Several groups have developed CT-aided stereotactic head frames for intracranial operations [6-10]. The brain is ideally suited for such procedures because of the availability of rigid

skull fixation and the absence of physiologic motion.

Recently, a CT-aided stereotactic body frame was announced [11]. An independent parallel effort in this direction was also in the testing stage [12]. These approaches extend precision stereotaxis to the whole human body.

Until now, all previous stereotactic techniques involved some stereotactic "frame." However, the use of a frame poses several problems: The manual reading and setting of the frame parameters is a slow process. It is tedious and error prone when frequent maneuvers are required. A motorized frame could help solve this problem, but such a system tends to be heavy and bulky. A frame is usually designed only for the head or body. Although a frame intended for application to both the head and body has been designed [12], to date its performance has not been satisfactory.

The fixed radius of a frame arch also lacks the flexibility that surgeons prefer. For example, the surgeon often wishes to place the probe holder as close to the patient as possible, which requires a small arch. But if one builds a frame with the

required small arch, it cannot be used with an oversized patient. Further, each frame, depending on its structure and design, has its unreachable corners. On occasion, the desired trajectory is within one of these forbidden zones of the frame. Finally, the frame structure hampers the surgeon's view of the patient and makes some surgical procedures quite difficult.

A new stereotactic technique eliminates all the above shortcomings by using a robot to replace a frame. Driven by a computer with sophisticated stereotactic software, such a system demonstrates tremendous advantages in accuracy, flexibility, time consumption, and convenience.

THE ROBOT SYSTEM

In order to choose a robot suitable for stereotactic purposes, several properties must be considered. The robot arm must have substantial maneuvering capability. Ideally, stereotactic surgery requires the surgeon to have complete access to position the arm and its probe. In addition, the arm must have an appropriate reach in order to provide an unobstructing support of the probe over the entire area. It must be sturdy enough to provide very stable

probe trajectory, and should have sufficient fail-safe features to prevent it from causing damage should it malfunction.

The robot system and its backup must be highly reliable to avoid breakdowns during surgery. The size and the weight of the robot arm should be as small and portable as possible. The robot is a surgical tool that the surgeon should be able to move about quickly during an emergency.

These considerations led to the choice of the PUMA 200 robot system by Unimation, Inc. This system consists of a mechanical arm and an electronic controller. The mechanical arm, as shown in Figure 1, has six joints. Each joint is driven by a permanent magnet servomotor through a gear train. For joints 1, 2, and 3 (waist, shoulder, and elbow motions), the motor incorporates electromagnetic brakes that are activated whenever power is removed from the robot. An external stand is designed to support joints 4, 5, and 6 for this research effort. All servomotors incorporate optical incremental encoders that provide position and velocity feedback to the robot's servosystem. The major hardware parameters for the PUMA 200 robot are summarized as part of Figure 1.

As shown in Figure 2, a custom-made probe holder is attached to the end effec-

tor of the robot arm so that the surgeon can guide the probe. The sleeve of the probe holder makes fine tuning of the probe length possible. A quick release mechanism allows the probe to be separated from the robot arm. This feature is useful for multiple targets. It is also necessary for body stereotactic patients because movement continues after the probe is inserted.

The electronic controller contains the built-in electronics for the robot system. The "brain" of the controller is a DEC LSI-11 minicomputer. The robot's VAL operating system software supports both serial and parallel input/output peripheral devices such as a CRT terminal, a floppy disk, and a manual control unit. The controller also contains digital and analog circuits to control each robot joint as well as its power supply. A manual control unit allows a user to manipulate the robot in several modes through buttons and a speed-control switch on the unit. When the panic button is pressed, all processes stop and every joint of the robot arm is frozen.

Since the LSI-11 microcomputer is designed for robot control only, it lacks the software needed for stereotactic computation programs. In addition, the robot system has to communicate with a CT scanner. Hence, a host computer is used

PUMA Robot	
Robot Arm	
Axes	Six revolute axes
Clearance Required	Spherical volume with shoulder at center: 0.47 m (18.5 in.) radius to hand mount flange.
Weight	129 N (29 lb)
Drive	Electric DC servomotor
Maximum Inertia Load (including Gripper)	Wrist rotation (J4) NOT exceed 1.0 in-oz-sec ² Wrist Bend (J5) NOT exceed 1.8 in-oz-sec ² Flange Rotation (J6) NOT exceed 0.5 in-oz-sec ²
Position Repeatability	±0.05mm (±0.002 in.) within primary work envelope
Tool Velocity	1.0 m/s (3.3 fps) maximum (with maximum load within primary work envelope)
Software Movement Limits	
Waist—Joint 1	-184 to 124 (308 degree)
Shoulder—Joint 2	-247 to 67 (314 degree)
Elbow—Joint 3	-56 to 236 (292 degree)
Wrist—Joint 4	-223 to 355 (578 degree)
Wrist—Joint 5	-122 to 122 (244 degree)
Wrist—Joint 6	-222 to 312 (534 degree)

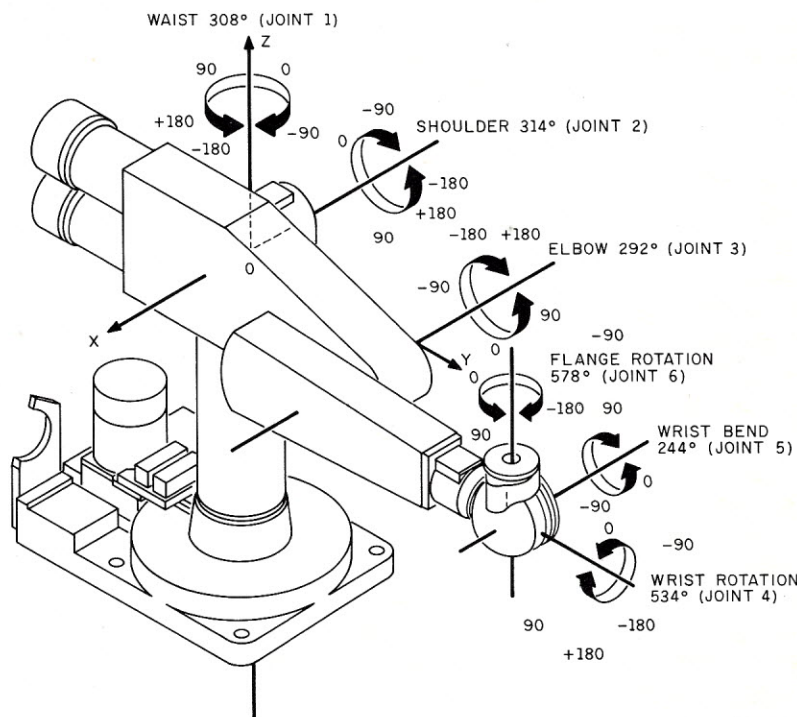


Figure 1. The Unimate PUMA Mark II Robot 200 series provides the precise, repeatable positioning required for stereotactic neurosurgery.

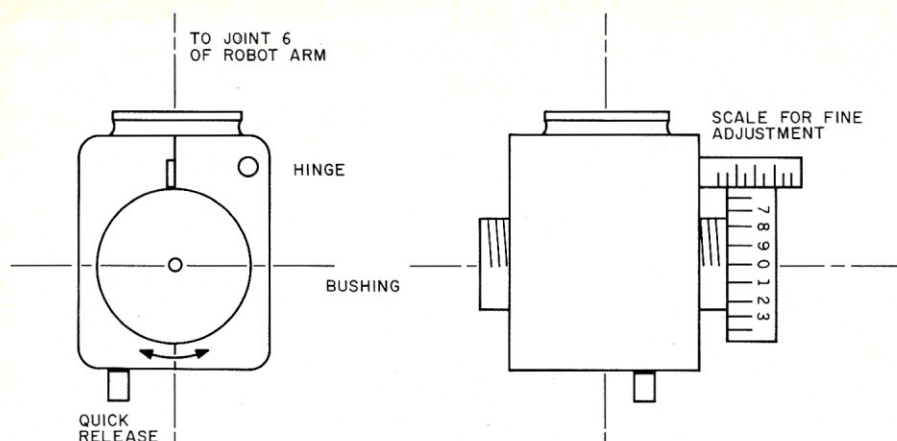


Figure 2. In stereotactic neurosurgery, the end effector is a custom-made holder for surgical probes. Fine adjustment of the probe is provided by a threaded bushing with vernier scale.

to store the scanned images and run all the stereotactic software. The host Data General Eclipse or DEC 11/34 minicomputer communicates with the LSI-11 via a standard RS-232 link. The surgeon interacts with the host computer using the stereotactic procedure software developed for this purpose.

THE ROBOTIC STEREOTAXIS SYSTEM FOR THE HEAD

In order to save on the development cost, a previously built stereotactic head frame was used in this experiment. With the arch removed, the ring structure supports and fixes the patient's head with a head rest and four stainless steel-tipped screw pins. Three N-shaped locators, mounted on the ring, determine the location of the scanned images. The ring in turn is attached to the scanner couch's sliding surface. This setup is shown in Figure 3.

The PUMA 200 robot is bolted to a pedestal. After CT images are taken, the patient is translated or slid out of the scanner to the robot's work area. Then the N-shaped locators are removed and the robot pedestal is attached to the metal ring as shown by Photo 1.

Next, the surgeon indicates a target point on one of the CT images. Using the trace of the N-shaped locators in the image and the known position of the ring, the X-Y coordinates of the target are transformed into the robot's 3-D coordinate system. Next, the surgeon maneuvers the robot arm to designate an appropriate entrance point on the skull. He also determines the approximate entry trajectory by directing the probe holder, illustrated by Figure 4. Such maneuvers

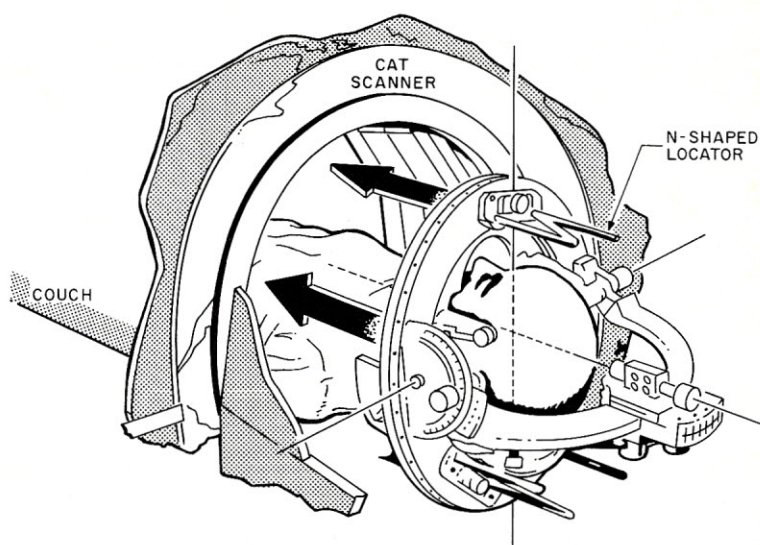


Figure 3. The head frame used in conventional stereotactic surgery was modified to save development costs. Its ring structure is clamped to the CT scanner's sliding carriage, with spatial position references provided by N-shaped locators that show up in the cross-sectional images obtained.

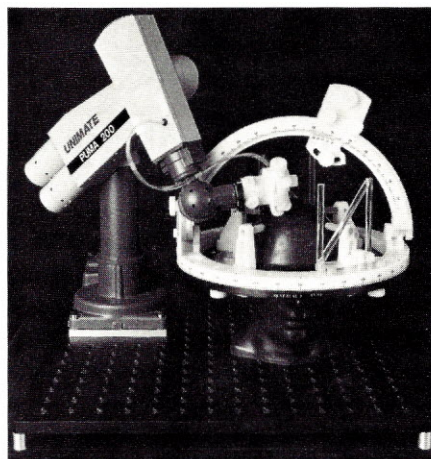


Photo 1. During surgery, the head frame, with the patient's head rigidly attached, is positioned on the robot pedestal at a precisely known location. This allows flawless mapping of CT scan information into robot positioning commands.

may be accomplished either by pushing buttons on the manual control unit or by setting the robot to the "free" mode and manually manipulating the robot arm.

Stereotactic software is then used to direct the robot arm to align the probe holder with the trajectory determined by the entrance point and the target. Initially, the robot arm is driven in such a manner as to be a safe distance away from the head. By pushing two buttons, the surgeon may control the robot so that the probe holder moves in or out along the trajectory (Figure 5) as close to the head as desired. The surgeon can use the buttons on the manual control unit to alter the tra-

jectory. Computer software maintains the probe holder trajectory line constantly pointing at the target as seen in Figure 6. Once the trajectory is determined, the probe holder is removed so that the surgeon can use the robot arm for a stable guide while boring a burr hole through the skull.

After the burr hole is drilled, the robot can be programmed to quickly retract to its standby position. As soon as the surgeon finishes cleaning and sterilizing the burr hole, the robot can be summoned back to the trajectory that it left. The probe holder and the probe are remounted on the robot arm and the surgeon is prepared for probe insertion. At this moment the surgeon can still modify the probe trajectory for slight adjustments. For example, a main artery might be avoided by a half-

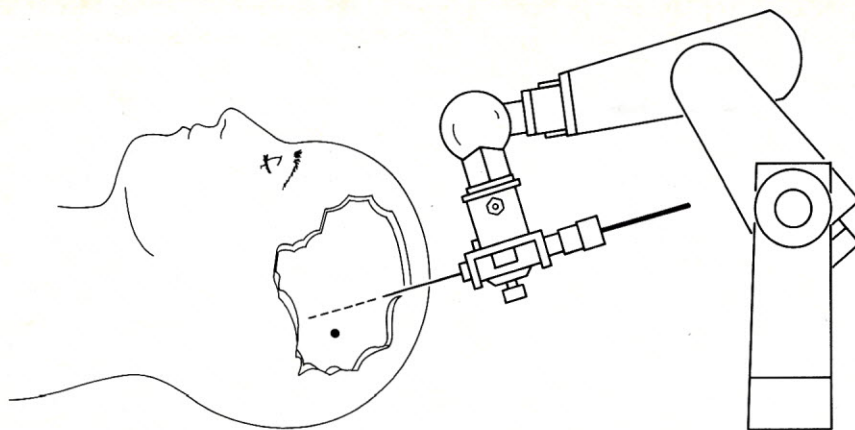


Figure 4. The robot and probe holder are first moved to the appropriate entrance point on the skull of the patient.

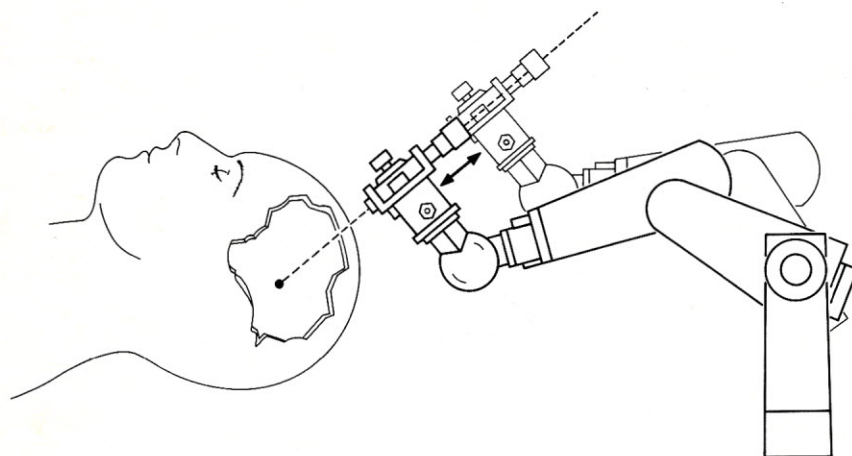


Figure 5. Using CT scan information, the surgeon selects a target point. Trajectories for the arm are then computed which will keep the probe centerline coincident with a desired centerline intersecting the target point.

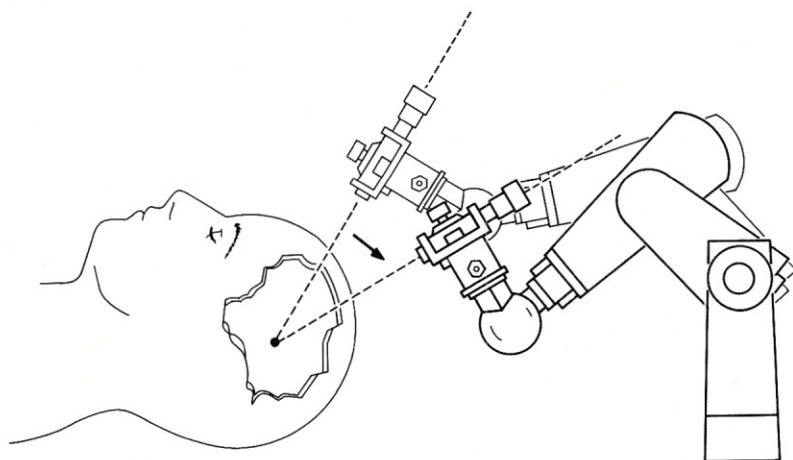


Figure 6. During alignment and setup, the software in the main computer keeps the probe holder's centerline pointed at the target.

inch shift. The surgeon can fine-tune the final trajectory by pushing buttons on the manual control unit in a manner similar to the use of a joystick. The stereotactic program maintains the probe direction, aiming at the target constantly.

Once the final trajectory is determined to the surgeon's satisfaction, he locks the robot arm by clamping the robot end effector with the external stand as shown in Figure 7. In this final configuration, the surgeon inserts the probe manually. A

threaded sleeve on the probe holder with a scale allows the surgeon to further increase or decrease the computed probe length.

In cases such as hypothermia therapy, the surgeon may need to access many targets through different paths. The above procedure can be repeated as many times as necessary. In fact, performing such procedure with a frame is impossibly tedious. Stereotactic software can direct the robot arm to access targets in parallel trajectories or any target and trajectory desired. After insertion, a quick release mechanism on the probe holder permits the probe or catheter to separate from the robot arm so the arm can move to another trajectory for reinsertion.

COMPARISON OF THE ROBOTIC STEREOTAXIS SYSTEM AND A SYSTEM USING A FRAME

The robotic system has several important advantages over the frame-oriented system. The robotic system is capable of fast, easy trajectory adjustments and is extremely flexible in its ability to allow for trajectory modifications. Such capability offers the surgeon a versatile tool. Sophisticated stereotactic operations can be performed by the surgical team with much less effort and time. Compared with the robotic stereotaxis system, the frame is a primitive method.

The robot eliminates human errors. The reading and setting of parameters in the stereotactic frame constitutes the major source of errors in a frame-oriented stereotaxis system. The robotic stereotaxis system does not require any human intervention, and hence eliminates the possibility for gross error originating from this source.

Robotic stereotaxis can be applied to both head and body. No existing stereotactic frame can apply satisfactorily to both head and body stereotaxis. Robotic stereotaxis has no fixed radius arch constraint. The arch structure in a stereotactic frame has two drawbacks: a) the surgeon cannot position the probe holder at an arbitrary distance from the patient, and b) in the case of the body frame system, the arch is sensitive to an oversized patient. The robot arm system has none of the above constraints. The robot lends a helping hand. When the surgeon needs a guide for probe insertion, the robot arm is a very capable assisting tool at the same time occupying only a minimum amount of space.

When not in use, the robot arm removes itself completely from between the surgeon and patient.

The robot allows wider access angles. The robot discussed in this article has six degrees of freedom. Hence, it offers an arbitrary trajectory at an arbitrary location within its working area. It has a much wider choice of accessing angles than a frame can be devised to do. The robotic system is capable of better accuracy. Though the precision provided by a stereotactic frame has proved satisfactory, with an angular precision of ± 2 arc-seconds in a typical head frame setup, the robot arm can provide an even higher accuracy. The robotic arm is capable of placing probes to a Cartesian coordinate precision of ± 0.05 mm. Such precision may be required in some delicate neurosurgery techniques.

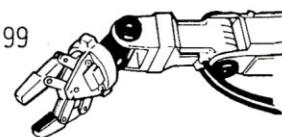
Finally, however, the robot does have new problems to be considered. For instance, it may reach a point or trajectory in many different ways. One must choose the preferred path required for safety and convenience. In other words, the software should provide a smooth, predictable path that risks the least chance of striking the patient or another object. Although it is possible to enter the environment contour information into the computer, at present it is considered time-consuming. Such problems can be handled reasonably well by three measures: a) letting the robot move in a speed sufficiently slow that a human can react in time, b) allowing the computer program to move the robot arm only at a distance sufficiently far from the patient to avoid damage, and c) keeping the manual control unit nearby. In an emergency the panic button can bring the robot system to a complete stop.

CONCLUSION

The robotic stereotactic procedure gives the surgeon a much more convenient tool to position probes than does the stereotactic frame. The software developed for these experimental procedures is not inordinately complex. We believe robotic stereotaxis may eventually become the core of an integrated computerized system for delicate surgery. When the system is coupled with a 3-D display and a desired radiation distribution pattern, the surgeon can perform internal radiation therapy very quickly and efficiently.

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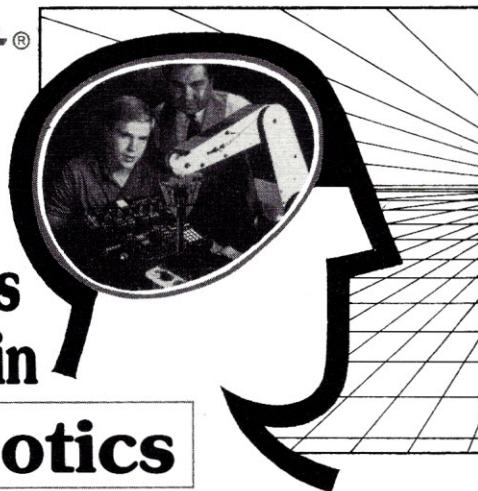
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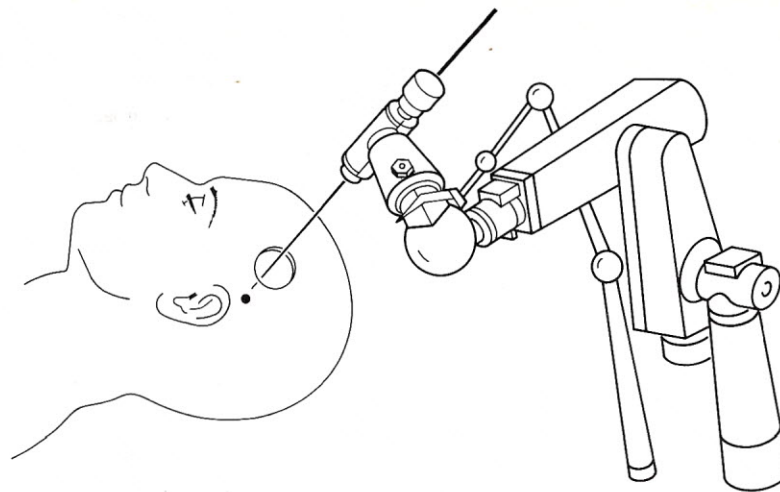


Figure 7. After the burr hole has been drilled and a final trajectory selected, an external clamp can be used to rigidly fix the end effector.

The PUMA 200 robot might not be the ideal robot to use for stereotaxis operation. However, it is currently the best among many candidates one can acquire with limited resources. The original intention of the present research effort was to demonstrate the effectiveness of using a robot in replacing a stereotactic frame. However, it has gone beyond that stage. The robotic stereotaxis system should continue to improve both in hardware and software to become a welcome helper to the surgeon performing stereotactic surgeries.

ACKNOWLEDGMENTS

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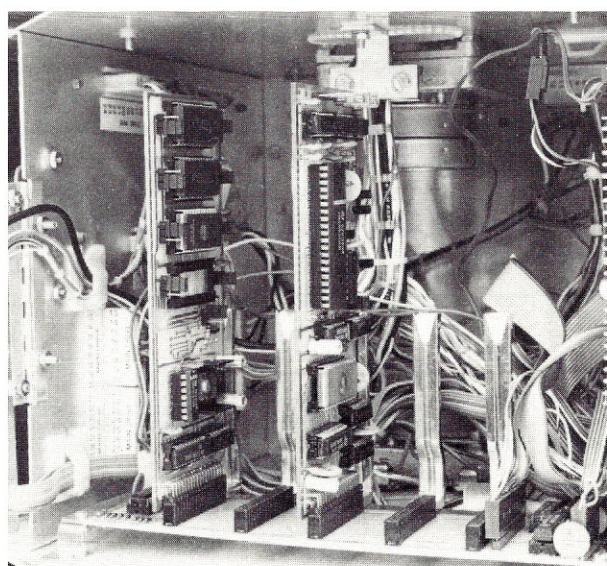
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A Z80-BASED, MULTITASKING CONTROL SYSTEM

Richard L. Weinbrenner
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This article describes a multitasking software control system (MTS) that runs on a Z80 microprocessor. MTS lets you structure a control process as if each device in the process (motor, sensor, and so on) had its own microcomputer controller. This is done with a multitasking supervisor program and an addressable bus. The end result is that, using only software, a programmer can link a device's input/output data stream to the input or output of a control routine.

In the control field, the actuators and sensors that make up a system may be located along the length of an assembly line or over the anatomy of a robot. The MTS bus consists of a flexible cable. Interface cards can be plugged in along the length of the cable to link the multiplexed bus data to a device.

Many tasks are self-contained but must signal, or communicate with, other tasks upon completion or upon realization that the task cannot be accomplished. The MTS software is designed to allow independent or interdependent process operation. Figure 1 is a block diagram of the system.

Multitasking Basics. Multitasking has been used on mainframe computers and minicomputers for many years. Some systems service hundreds of terminals at once, and each user has the illusion that he or she has full use of the computer. The computer accomplishes this feat by running one user's program for a short time, then running the next user's program for a short time, and so on. If there are ten users on the system and each user's program is run for one second, each user sees a one-second spurt of activity every ten seconds. In practice, the cycle time is much faster, and each user thinks that operation is continuous.

In large multiuser systems, the programs can range from several thousand bytes to tens of thousands of bytes and can change size from user to user and from moment to moment. A dynamic memory-allocation scheme is required for such a system.

MTS, on the other hand, assumes the system designer will specify all of the tasks and communication channels in the design stage of the system. Although these factors may change as a system is developed, the final version will be static in the sense

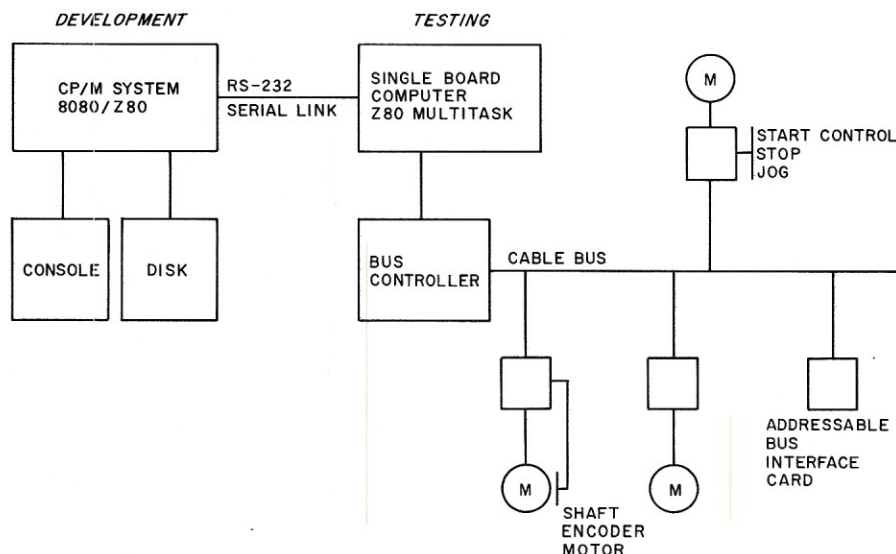


Figure 1. A block diagram of a typical MTS configuration.

that all tasks will be permanently allocated in memory. MTS uses simple round-robin scheduling.

Design Requirements. When designing MTS, I set three main requirements. The task must be able to run transparently; that is, the program must be written, and should behave, as though each task is the only one that the computer is executing. This can never be absolute, of course, but it can be approximated to a high degree. The second design requirement is that each task should be able to communicate with other processes running in the same microcomputer and with external devices and processes. The final requirement is that the system should also serve as a program development tool.

The first requirement is met by the MTS supervisor program; the second is met with the MTS pipes subsystem, which is explained below. The third requirement is met by the monitor program, which lets you use an existing microcomputer as a development tool.

Hardware Requirements. I developed the necessary utilities to run MTS using a CP/M-based microcomputer, but you could use any system that generates 8080 or Z80 machine code and that can download this code using a serial port. It is possible to run MTS using any Z80-based microcomputer that supports clock interrupts and that does not disable the interrupts for hardware functions such as disk accesses and display updating.

Two counter/timer channels are dedicated to the task interrupt and the real-time clock interrupt. Although it would be

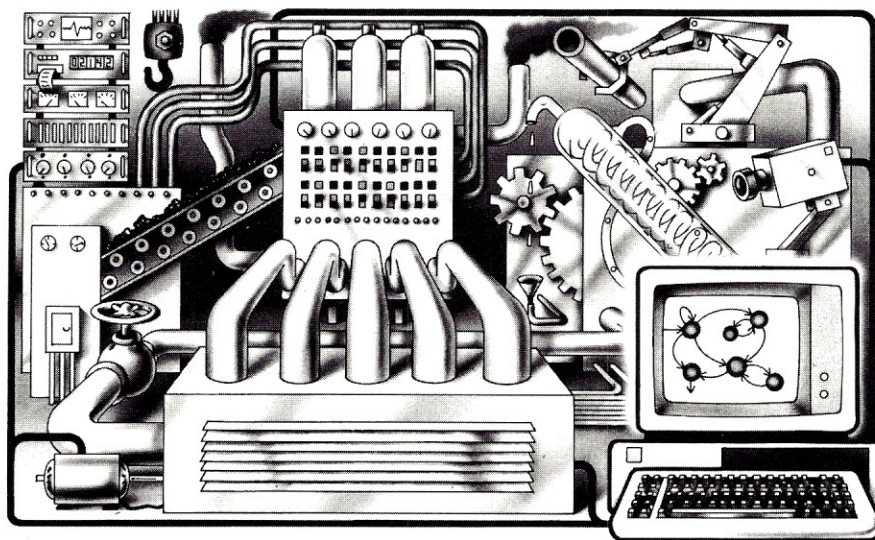
possible to combine the real-time and task interrupts, it is more convenient to be able to experiment with different task interrupt rates without having to adjust the clock routine. The current MTS system requires under 2 Kbytes ROM and requires approximately 256 bytes of scratch and buffer memory.

The Supervisor Program. One channel of the counter/timer chip generates an interrupt of a fixed time interval of 1/50 to 1/100 of a second. Each time this interrupt is received, MTS switches to the next process to be run. The frequency of the interrupt is called the task switch rate. Another important parameter is the overhead, or task switch time—the amount of time required for MTS to switch from one task to the next. With the Z80 running at 4 MHz, a task switch takes less than 150 microseconds. This overhead would decrease if the CPU clock speed were increased.

The overhead percentage can be computed using the switch rate and the switch time, as follows: Percent overhead = (switch rate) × (switch time) × 100. For example, with a 4-MHz clock rate, a task switch rate of 100 per second, and a switch time of 150 microseconds, 0.015 second is used in a one-second period, or 1.5 percent of processor time.

To keep track of all the parameters relating to a task, each task is assigned an 8-byte task queue block (TQBLK), which holds the data that the supervisor needs to save and restore each task and to specify execution options that are designed into the system (Figure 2). Each task is considered to require contiguous memory between a task base address (TBADR) and a task end address (TEADR).

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TASK QUEUE BLOCK

TASK BASE ADDRESS	0	WORD-LOW, HIGH BYTE
TASK END ADDRESS	2	WORD-LOW, HIGH BYTE DEFAULT STACK POINTER
PRIORITY COUNTER	4	BYTE
TASK PRIORITY	5	BYTE
WAKE-UP TIME	6	WORD-LOW, HIGH BYTE POINTER TO TIME STS

Figure 2. Details of the task queue structure. The task queue is composed of 8-byte queue blocks.

Switching Tasks. Switching tasks is a three-step process. The program saves the state of the current task, selects the task to be run next, then restores that task to its last running state.

Upon receiving an interrupt, the program saves the state of the current task by first saving the contents of all registers on the current task's stack, using the Z80's PUSH instruction. The value of the program counter (register PC) is pushed on the stack when the interrupt is received. It is important to keep the task switching overhead as low as possible. In MTS, it is assumed that the Z80's alternate register set is dedicated to the input/output interrupt-service routines; thus the alternate register set is not saved.

To select the next task, the Z80 IX register is set up to index the task queue block in the task queue. At this point, the program can deal with the parameters for the task without having to know which task it is. All parameters are referenced relative to the IX (index) register:

```
SAVE_STATE_OF_CURRENT_TASK:
PUSH IY
PUSH IX
PUSH HL
PUSH DE
PUSH BC
PUSH AF
LDA,(CURTSK) ;IX=CALL TIDX TASK
QUEUE BASE+(CURTSK * 8)

;save the current task's stack pointer
LD HL,0
ADD HL,SP
LD (IX+TSPTR),L
LD (IX+TSPTR+1),H

;reset this task's priority
LD A,(IX+TPRTY)
LD (IX+TPCNT), A
```

Next, the system computes which task to run next:

```
SELECT_NEXT_TASK:
LD A,(CURTSK)
INC A
CP TNUM ;set to first task
```

```
JR NZ, PRIORITY
LD A,0 ;when we reach last task
```

```
;decrement the task's priority number
PRIORITY:
DEC (IX+TPCNT)
JR NZ, select_next_task
```

```
RUN_NEXT_TASK:
LD (CURTSK), A
CALL TIDX
```

```
;restore the task stack pointer
LD L,(IX+TSPTR)
LD H,(IX+TSPTR+1)
LD SP,HL

;restore the task's registers
POP AF
POP BC
POP DE
POP HL
POP IX
POP IY

;restore the task program counter by returning
RET
```

Supervisor Calls. A set of calls is available to let the programmer fine-tune the system to its application. One such call lets a task "give up" its time slot. This can improve the system's efficiency if, for example, a task must wait for a status change to occur before it can proceed. Instead of wasting processor time in a wait loop, the task can use the TRETRN call. This call's effect is similar to that of the hardware task interrupt—it lets the supervisor immediately switch to the next task.

The TINVOK call lets the system bypass the next process selection. The caller simply specifies the next task number and the system immediately passes control to that task. The THALT call prevents the system from switching to the next task, and the TRUN call reenables task switching.

Pipes Subsystem. MTS uses a general-purpose subsystem to allow interprocess communications. A pipe is a first-in, first-out buffer that can be from 2 to 255 bytes long. Pipes are supported by open, write, read, and lock calls. The pipes subsystem is independent of the supervisor program. The programmer may open as many pipes as required.

Pipes let tasks communicate with each other. Using pipes, tasks can be interconnected much as electrical circuits are connected. Tasks can be designed with one input and many outputs, or with many inputs and one output. Figure 3 illustrates a simple system of three tasks and four pipes.

Five calls are available to a task for using the pipes system. A task must first define a pipe using the POPEN call, which specifies the size and buffer location of the pipe. POPEN places this data into an index much like the task queue. All subsequent calls to the pipes subsystem index this information by pipe number (Figure 4). The following illustrates a typical write-to-pipe operation.

Continued on page 28



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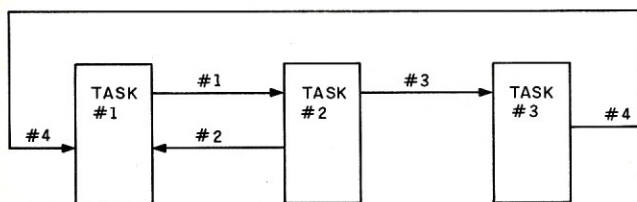


Figure 3. A sample pipe system consisting of three tasks and four pipes.

```

;typical write to pipe from a task
;load registers with channel number and character to write
LD A,5 ;channel number 5
LD C,'x' write 'x' to pipe
TRYAGN: CALL PWRITE ;'Z' FLAG SET IF PIPE WAS FULL
JR NZ,SUCCESS
CALL TRETRN ;give up time slot
JR TRYAGN
SUCCESS: (program continues)
  
```

Some Examples. The following examples show how pipes and tasks could be used under the MTS system.

Applications often require some action upon the receipt of stimulus. This stimulus may be composed of several inputs, and it may be that only a certain combination of inputs during a certain operation demands a response. One task could be defined to monitor these multiple inputs and to generate a signal based on matching certain criteria. This structure is called a filter.

PIPE DESCRIPTOR

PIPE BUFFER ADDRESS	0	WORD-LOW, HIGH BYTE POINTER TO BUFFER
PIPE WRITE POINTER	2	BYTE-POINTER RELATIVE TO BUFFER
PIPE READ POINTER	3	BYTE-POINTER RELATIVE TO BUFFER
PIPE SIZE	4	BYTE-SIZE SPECIFIED IN POPEN CALL
PIPE CHARACTER COUNT	5	BYTE-COUNT OF CHARS AVAILABLE TO READ
PIPE WRITE STATUS	6	BYTE-SEE PSTAT1 DETAIL
PIPE READ STATUS	7	BYTE-SEE PSTAT2 DETAIL

PSTAT1 BIT 7 - 1 IF LOCKED FOR WRITE
 BIT 6 - 1 IF OPENED
 BITS 5-0 - CONTAINS THE TASK NUMBER OF THE
 TASK THAT HAS THE WRITE LOCK.

PSTAT2 BIT 7 - 1 IF LOCKED FOR READ
 BIT 6 - UNDEFINED
 BITS 5-0 - CONTAINS THE TASK NUMBER OF THE
 TASK THAT HAS THE READ LOCK

Figure 4. Details of the pipe index structure. The pipe index is made of 8-byte descriptors. The descriptor for pipe channel 0 is located at the base of the index, the descriptor for pipe channel 1 is at the base plus 8, and so on. The descriptor contains the address of the buffer being used by the channel, the character count, 8-bit relative read and write pointers, and two status bytes, one each for the write and read functions.

At times, it may be necessary to send the output of one task to a number of other tasks (Figure 5). A format could be designed that would specify the destination of the data. In Figure 5, multiplexed data is received from a port, and the hardware interrupt process writes this data to pipe 1. The external process may have the ability to direct data to task 2, 3, or 4, provided that a protocol has been defined for task #1. A simple protocol might be a 2-byte sequence consisting of a destination address byte followed by a data byte. Task 1 could read 2 bytes at a time and deliver only the data byte to pipe 2, 3, or 4, as specified by the destination byte.

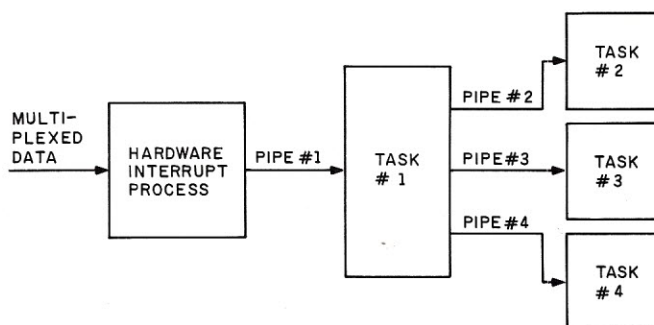


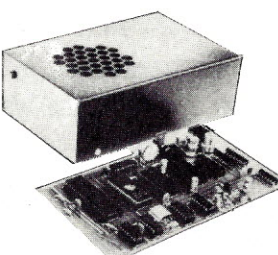
Figure 5. Sending the output of one task to a number of other tasks. In this arrangement, task 1 demultiplexes the data stream and sends a message packet to the task specified by the protocol.

In practice, the designer might choose a more complex method to allow for variable-length data fields, to ensure proper synchronization, and to provide for error checking. In this case, task 1 would serve as a demultiplexer. Figure 6 illustrates the opposite concept—multiplexing the output from multiple tasks into a single serial data stream.

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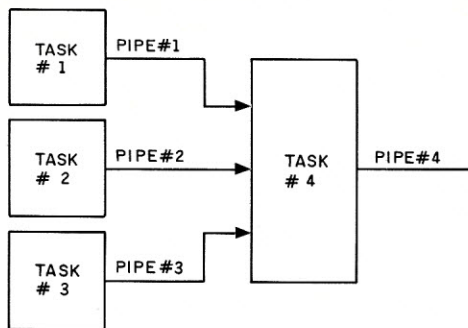


Figure 6. Multiplexing the output from multiple tasks into a single serial data stream.

The pipe locks provided in MTS allow a similar multiplexing function using one pipe and no additional tasks. Compare Figure 7 with Figure 6. The scheme in Figure 7 performs a similar function using pipe locks. The locking capability is required for any message with a length greater than 1 byte. If the protocol defines a message format of 4 bytes, the process must write those 4 bytes to the pipe contiguously. If no lock was present, another task could write data interspersed before the entire 4-byte message was written, and the task reading the other end of the pipe would misinterpret the data.

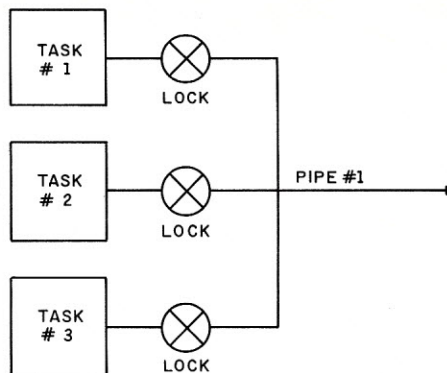


Figure 7. This arrangement uses pipe locks to perform a function similar to that of Figure 6—sending data from multiple tasks to one task.

format is compatible with standard CP/M hex-format files, which lets the user create tasks with the CP/M's ASM program.

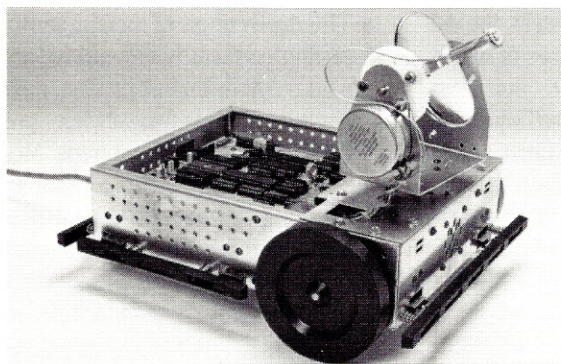
Besides providing task-debugging commands, such as task break and run supervisor, the monitor provides standard monitor commands, such as dump memory, fill memory, substitute memory, and jump to address. The pipes and supervisor calls are reentrant, allowing the programmer to use them freely in a task. At present, the programmer must allocate memory to each task.

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RECOGNIZING PARTS THAT TOUCH

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Almost all commercially available vision systems for robots that locate randomly positioned parts are based on the SRI International vision module [5]. These systems extract "blobs" from binary images via connectivity analysis and then compare the blobs with pretaught models in order to recognize them. Users train the systems by simply showing them examples of the objects.

Systems like the SRI vision module, while efficient, have a limited application scope. There are two major technical limitations: 1) objects must be in high contrast with the background and 2) objects must be spatially separated, lest their images become merged into a single blob. For many applications, the high contrast requirement can be satisfied by using structured light. An excellent example of this technique is the Consight system, which is used in conjunction with a conveyor belt [6]. The second limitation, however, is not so easily overcome. The SRI method uses a combination of area, best fit ellipse, perimeter, and second moments to represent shape in order to recognize objects and determine their orientation. These object descriptors fail when objects are so close together that their images merge into a single blob.

The new vision system developed by Adept Technology significantly relaxes the requirements of high contrast and non-touching parts. This system uses a new approach to part recognition. Objects are characterized by their distinctive corners and edges (local features) instead of their gross area characteristics. This article

describes the effort that led to the system's development and how the system operates.

BACKGROUND

When the vision project was initiated, its aims were 1) to survey the visual characteristics of industrial parts and their environments and 2) to search the image-processing literature for promising new approaches to the problem of locating and identifying parts.

The primary purpose of the parts survey was to determine the desired application coverage for the new vision system. We did not concern ourselves with issues of system cost and speed, since these technical requirements would be considered when different approaches were investigated. Based upon the analysis of information obtained from a company survey of potential robot customers and from studies and surveys of industrial parts by others, we concluded that:

- Most parts are combinations of three-dimensional solids of rotation and prismatic solids. Such parts have two-dimensional image projections consisting of lines and ellipses. The most common curved projections are circles, ignoring the slight distortion due to perspective.
- Nearly all parts are rigid or, at worst, only slightly flexible. Wires are probably the most common exception to this observation. When present, wires are an extra complication. Often they

are partially invisible at standard camera resolutions.

- Most parts have holes, and almost half have holes completely through them. The holes are usually orthogonal. Many holes pass through objects completely, so they are visible given backlighting.
- Most parts have a silhouette that uniquely determines orientation in their resting plane. Many parts have upside-down ambiguity given a silhouette only. However, part presentation is usually not completely random, and not all parts are stable upside down.
- The depth of parts (height above the resting surface) is dependent on the mode of manufacturing. Cast, molded, and turned parts typically have greater depth than sheet metal parts. Most of the parts surveyed that a robot would likely handle had significant depth.
- Uniform reflectivity and high contrast with the background are unusual. Sheet metal parts and machined parts, probably the majority, reflect specularly. The positions of such reflections depend on the position and orientation of both the part surface and the light source.

In addition to part characteristics, we found that the transport mechanism is also an important factor in determining the desired capability of the vision system. In order of occurrence, parts are transported in bins, pallets, conveyors, and by miscellaneous means (such as by hand). Current and near-term robot applications, however, involve conveyors and pallets.

An extensive search of image-processing R&D literature was performed in the hope of finding good ideas for the vision system design. Literally hundreds of vision papers were read and recorded in an annotated bibliography. As a result of the literature search, the "feature-based" recognition method was found to be the most promising. This approach uses spatially inter-related boundary features such as lines, arcs, corners, and holes to visually model objects. By comparing features in the image with features in pretaught models (prototypes), objects in the image are recognized. Since recognition is based on boundary segments and not on "boundary totals," objects may be recognized even when their boundaries appear incomplete due to low contrast or overlap.

Noteworthy research into the feature-based method has been performed by Bob Bolles of SRI International [1, 2] and Walt Perkins of General Motors Research Labs [7, 8]. They did not produce complete, practical vision systems, but they did demonstrate the basic ideas.

As a result of the parts study and literature search, we decided to initiate a project to develop an industrial feature-based vision system. The challenge would be to make it robust, practical, and easy to use. A robust system should be able to recognize a wide range of parts that are presented by conveyors or pallets. To be practical, the system would have to be microprocessor-based and yet quickly process images. Finally, to simplify its use, recognition training would have to be highly automated.

SYSTEM OVERVIEW

The new vision system resulting from our development work uses a feature-based object-recognition algorithm. It is microprocessor-based and operates quite fast, recognizing multiple objects per second. It is now integrated in Adept Technology's robots with the VAL-II robot control system [9].

The system processes binary images provided by a solid-state camera. Although the input image is only binary, the system does edge-type processing to extract object boundary features, such as lines, arcs, corners, and holes. The characteristics of these features and their relative spatial relationships provide an effective visual representation of the image.

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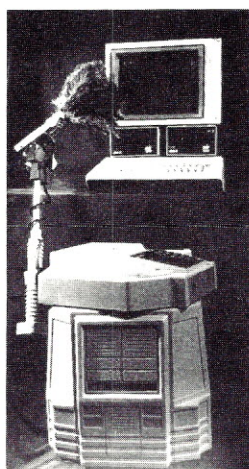
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The vision system compares boundary fragments (the features) in the image with the features of known prototypes. The prototypes are generated during a training session in which the system is shown sample parts. When the comparison of one or more features is positive, a match is proposed that places the prototype in a particular position and orientation in the image. The prototype-to-image match is then verified by traversing the entire boundary of the prototype, looking for further evidence of its presence in the image. A threshold parameter, prespecified by the user, determines how much of the boundary must be visible for match acceptance.

The vision system operates with either a linear array camera over a conveyor belt or an area array camera over a pallet or similar working surface. The conveyor application is more complicated than the area for various reasons: the conveyor image data arrives only a line at a time at a variable rate, the image is "infinitely long," and image coordinates along the conveyor must be kept in synchronization with the manipulator's tracking coordinates.

Since the linear array camera interface encompasses all the problems of an area array interface, we will use it for purposes of discussion.

Hardware. The vision system is part of an integrated robot controller that shares various hardware and software resources. The heart of the vision system is a Motorola 68000 10-MHz processor. It shares a backplane with other processors, one of which executes the VAL-II robot control system [9]. VAL-II is the master process through which all user input and output to the vision system passes.

In addition to the processor and memory, the vision system consists of a solid-state, linear array camera (256×1), a high-resolution monochrome display, a graphics display interface board, and a camera interface board. The robot's conveyor tracking hardware is used to synchronize camera data acquisition with the conveyor movement. The camera is strobed whenever the conveyor moves a fixed unit of distance, so the conveyor may move at a variable speed and even stop for an indefinite time without loss of image data or synchronization.

The camera is usually mounted directly over a conveyor belt. The camera interface

board thresholds the image data as it arrives and presents the data to the vision processor as run-lengths (the column numbers where black-to-white or white-to-black transitions occur). The implied object boundaries are simultaneously displayed on the video monitor, and the monitor image is scrolled to reflect the conveyor movement. All subsequent processing of the image data is via software.

Algorithms. In its normal execution mode, the vision system performs operations on the image data in sequence. As the camera provides sensory data on a line-by-line basis, connectivity analysis is performed and the scrolling display image is updated. When a region closes off (the trailing edge of the object passes under the camera), the vision system processes the region's boundary. This processing involves multiple steps, producing multiple boundary representations, the last of which is a connected sequence of lines and arcs. Finally, recognition is performed by comparing features of the boundary with those of the prototype models.

There are seven steps to the image processing:

- 1) Connectivity analysis
- 2) Chain encode perimeters
- 3) Fit edges to chains
- 4) Fit lines and arcs to edges
- 5) Classify corner features
- 6) Propose prototype-image matches
- 7) Verify match.

An object is located and properly identified when all seven steps are successfully completed. At that time, the object's identification, position, 2-D orientation, and "goodness-of-appearance" measure are sent to the VAL-II processor. This information is then available to user programs written in the VAL-II language.

Connectivity Analysis. This is the common SRI International technique for separating closed regions from the background. The processing is performed in a single pass across the binary image—appropriate for "infinitely long" conveyor belt images. Input to the connectivity analysis is the output of the camera interface hardware: run-length encodings on a line-by-line basis. This compact image representation is simply a list of the column numbers where there are "color" transitions of black-to-white or white-to-black. Whereas the

camera interface hardware groups contiguous horizontal pixels of the same color into run-lengths, connectivity analysis groups contiguous vertical run-lengths of the same color, thereby completely segmenting the image into black and white regions. While processing the run-length encodings, the algorithm also computes the area and perimeter of each region. Finally, as regions close off, they are interrelated via parent, child, and sibling relations. A hole in a region is a child of the outer region, and the outer region is a parent of the inner region. Two holes in a region are mutual siblings. See reference [3] for a published Pascal program that does connectivity analysis based on run-length encodings.

Connectivity analysis is performed on a line-by-line basis in response to interrupts from the camera interface board. All subsequent processing, steps 2-7, is performed in the background (i.e., not interrupt driven) for each complete region.

Chain Encode Perimeters. Processing proceeds with this step after the outermost region, whose parent is the background, closes off. This step produces a chain-encoding representation of the region's perimeter. Using the stored run-length encodings with their region associations provided by connectivity analysis in step 1, a string of right, up, left, and down moves is produced that will traverse the region's perimeter [4]. Figure 1 shows a plot of the chain-encoded boundary of a region. The region is "black," depicted by a dotted pattern.

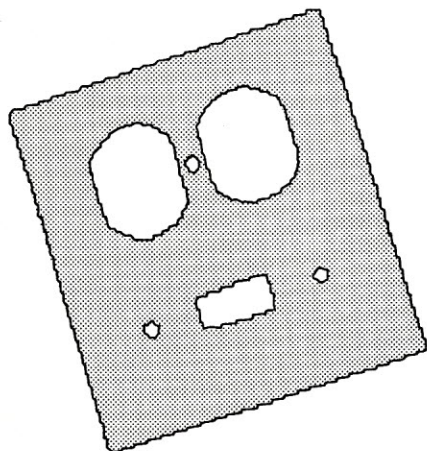


Figure 1. The second step in recognition is to chain-encode the edges of regions, a process that produces a staircase-like sequence of right, up, down, and left movements along pixel boundaries. This is the last form in which image data will be directly tied to its original X-Y pixel grid form.

Fit Edges to Chains. This step fits straight line segments to the chain encodings in order to produce a more succinct representation of the region's perimeter. The algorithm used is efficient and the edges produced accurately approximate the chain encoding. A benefit of the algorithm is that the jagged (quantized) edges represented by the chain encoding are smoothed. After this step, the chain-encoding data is discarded. Figure 2 illustrates the edges fit to the chain encoding in Figure 1. Corners are drawn as knots on the edges.

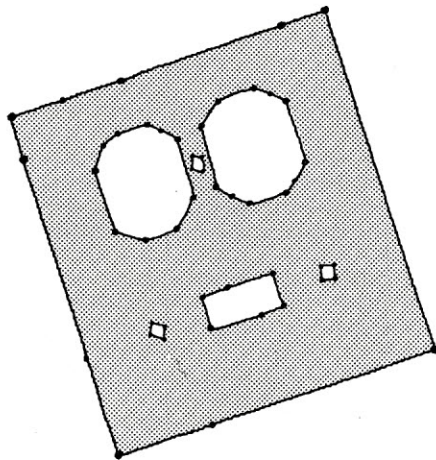


Figure 2. The third recognition step is smoothing the chain-encoded representation into a more concise series of straight line segments. Here we show such an "edge fit" of connected line segments applied to the chain-encoded image of Figure 1.

Fit Lines and Arcs to Edges. This processing step fits straight line and circular arc segments to the edges produced in step 3. This step is relatively expensive in processor time, but the expense is well-justified. First, lines and arcs are fit to within a user-specified tolerance, so image smoothing is controlled. The result is a further data reduction, especially when the parts are circular or have circular holes. Industrial parts studies have shown that the majority of parts are prismatic and rotational in shape, so their two-dimensional projections as images are naturally represented by lines and arcs. The final justification for fitting lines and arcs, as opposed to fitting lines only, is that they provide a greater variety of edge and corner types, making recognition easier. Figure 3 illustrates the lines and arcs fit to the edges in Figure 2. (Note: The lines and arcs fit are not always this clean. The real world of parts images is usually not as simple as in these examples.)

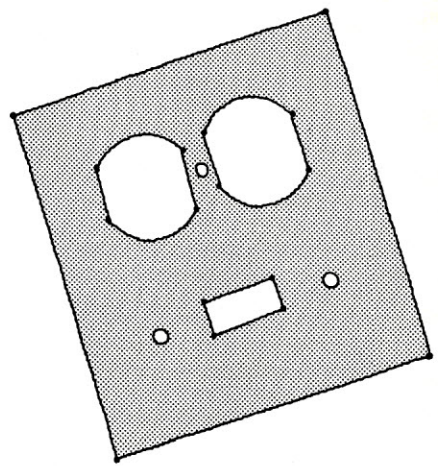


Figure 3. The fourth step in the feature-based recognition method is reduction of edges to a series of connected straight lines, arcs, and circles. While computationally expensive, this step produces the most concise representation of the image.

Classify Corner Features. This step classifies all connected edge-edge pairs, where the edges are the lines and arcs from the previous step, and associates them with the corner classes of the known prototypes. The corner classes are chosen during training, based on the objects the user wants the vision system to recognize. Generically, there are only a few types of classes: line-line, line-arc, arc-line, arc-arc, and circle. In addition, there are the wildcard variations: line-any, any-line, arc-any, and any-arc. The "any" refers to an edge that may belong to a different object because two parts touch or overlap.

Although there are only a few generic types of corners, each of the prototype's corner classes has specific parameterized definitions. An acceptable minimum and maximum included angle (the angle formed by the two edges) is associated with each corner class. Also, acceptable minimum/maximum lengths are associated with each line edge of a corner class. For arcs there are acceptable minimum/maximum angular ranges, minimum/maximum radii, and a convex/concave indication.

Each edge-edge pair in the image is compared with all corner classes. When the types correspond and the measures of the edge-edge pair fall within the acceptable ranges of the class, the edge-edge pair is placed on the corner class's association list. Some edge-edge pairs in the image may not be associated with any classes, whereas others may be associated with many.

Propose Prototype-Image Matches. This step proposes that prototypes are present in the image at specific positions and orientations. These prototype-to-image match proposals are based on the corner classification made in the previous step. During training, the corner classes are ordered according to uniqueness and "clarity." At run-time, in this order, each class is considered until all image edges have been accounted for or until all possible matches have been proposed. Each image corner and prototype corner associated with a class is a possible match. However, such matches must be confirmed before an official proposal can be made and the final step begins.

Confirmation is a partial verification (see **Verify Match**, below) that is required when more than one prototype corner is associated with a corner class. Even if only one corner is associated with a class, confirmation will be used if the prototype is complex (has many edges), so that mismatches will be detected before the expensive verification step. The need for confirmation is determined during training when corner classes are chosen. Associated with each prototype corner is a list of the confirming corners that, if present in the image at the same relative position, would distinguish it from others. Nearby corners are chosen as confirming corners when appropriate because they are more likely to be visible (not occluded) along with the corner to be confirmed.

Verify Match. Given a single prototype-to-image match proposal, this step verifies the prototype's presence in the image. The prototype's boundary representation is transformed to the image via the two-dimensional translation and rotation. A search is made for image edges that align with the prototype edges. The close-enough test is to be within a user-specified tolerance. Although the signs of the edges (black-to-white versus white-to-black) must correspond, the edge types do not. So lines verify arcs and vice versa. If enough of the prototype's boundary is present in the image, the match is accepted. "Enough" is a weighted threshold, specified by the user during training.

Figure 4 shows the result of three match verifications. For each proposed match, the prototype was drawn overlaying the image. Edges that were verified are shown with

solid lines. Edges not verified are shown with dotted lines. All the figures shown as simplified line drawings in this article can be used as display output modes.

OPERATION BY THE USER

The vision system provides user commands for enabling and disabling switches, setting parameters, calibrating, training, and storing/loading prototype models to and from disk.

Calibration is needed to determine the Y/X ratio, where Y is measured along the length of the belt in strobe units and X is the visible width of the belt in pixel units. To calibrate, the user simply sends a large circular object down the belt under the camera. The vision system fits an ellipse to the image of the object in order to compute the proper pixel/strobe ratio. This ratio is subsequently used to scale the X component of all image coordinates, thereby making the image square (i.e., circles will look circular and not elliptical).

Training the vision system to recognize specific parts is relatively easy for the user because it is highly automated. The system can be trained to recognize up to 10 different objects at a time. An unlimited number of prototypes may be stored on

disk, however, from which up to 10 at a time may be selected.

To train the system on a new prototype object, the user types the name of the object and then sends an example of it under the camera. The system processes the image through the line and arc fitting step (see **Algorithms**). The result of the line and arc fitting is displayed on the video monitor as in Figure 3 so that the user can edit it to clean up the system's model of the part topology. By topology, we mean the edge types, lines or arcs, and the number and approximate location of the corners. Each trained instance of the part must have the same topology. The user edits the model by moving a cursor around the screen and typing an edit command:

- D to Delete a corner
- C to Create a corner
- A to convert a line to an Arc
- L to convert an arc to a Line
- R to delete an entire Region (i.e., hole)

The effect of the edit command is instantly displayed. When the user has finished editing an example and the example is not the first instance of the prototype, the system compares the topology of the example with that previously taught to ensure one-to-one correspondence. If they do

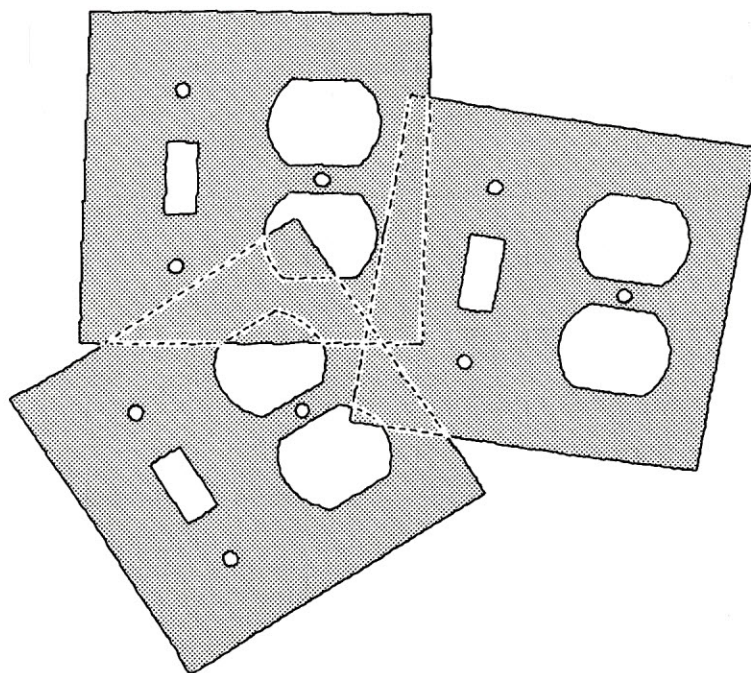


Figure 4. An example of matching a complex case of three overlapping objects. The verified matches are shown as complete objects with dotted lines corresponding to proposed overlapping portions.

not match, the system displays the previously taught prototype next to its new instance while blinking the edges that differ. The user may then re-edit the new instance.

Via training, the system collects mean and standard deviation statistics on the dimensions of the parts. The more examples of the part given, the better. As a general rule, the user should train the system on a dozen examples. With a little experience, training the system on a dozen examples of a single object type should take less than 10 minutes.

One other training option is to assign weighting factors to edges. This is useful for inspection applications where, for example, the presence of a hole or group of edges is important to distinguish good parts from bad ones. The weighting factors are used during the final verification stage of image processing.

A large section of the vision system software is dedicated to training. Part of this program implements the user interface, but a large and complex part is devoted to automatically analyzing the known prototypes and filling in the recognition strategy tables. These tables are used to automatically determine the recognition strategy, part symmetry, and ambiguous similarities between parts. Corner classes are chosen, confirming corners are picked that will disambiguate matches, and all lists (e.g.,

of all corner classes) are ordered to optimize processing speed.

PERFORMANCE

Run-time performance measurements were made of the vision given two types of objects: light switch cover plates and chocolates. Each cover plate is a combination of one light switch and two power receptacles as shown in Figures 1-4. The cover plate exercises many of the variations in shape expected: lines, arcs, circular holes, rectangular holes, and corners formed by tangentially joined lines and arcs. The chocolates are the kind that are packed in boxes and given to sweethearts on Saint Valentine's Day. Three different chocolate shapes were tested: round, square, and teardrop shaped. The chocolates posed special problems because they vary in size by up to 20 percent; they have significant flashing along their base, which makes their silhouette shapes vary; and they have almost no distinctive features with which to trigger the recognition process. However, they have few edges, so processing is fast, even though extra verifications are sometimes needed to disqualify wrong match proposals.

The vision system recognized about two overlapping cover plates a second. The system recognized about eight chocolates per second in touching combinations.

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In The Robotics Age

Edited by Stephanie vL Henkel

The oracles of industry do not always speak in unison. For instance, either more or fewer flexible manufacturing systems will be delivered, and prices will either drop or remain stable. It all depends on whom you read. What *is* certain, however, is that industrial robotics is receiving a great deal of attention from market analysts, indicating the permanence of robots in the workplace.

A survey of end users of machine vision systems conducted by Prudential-Bache indicates both a high compound annual growth rate (CAGR) and a fragmentation in the industry—dozens of companies are in the field, but most have revenues of under \$5 million. Machine vision is described in the report as a “very difficult industry and one in which the high near-term CAGR may be the result of many of the vendors simply growing from a very small base level.” The report goes on to state that the vision industry does not lend itself well to large companies, despite the growing number of large vendors. The number of unit volumes and the size of the profit margins required for a major company to get into a new industry have been disincentives to all but a small number of the country's larger firms.

Among other findings of the survey:

- The automotive and electrical/electronics industries are dominant end users, with a “huge preponderance” of vision systems going to the Midwest.
- The average price of a system, after eliminating the extremely high-priced models, is about \$50,000.
- Nearly 60 percent of the survey respondents expressed a

MARKET SUMMARIES AND PROGNOSTICATIONS

preference for generic and flexible systems as opposed to those more tailored to a particular application.

- Technology, service/support, and applications engineering were the most important factors reported by end users as influencing their buying decisions.

- End users on average do not expect prices to decline in 1985. (In an earlier survey, vendors had rated technology as far less important and said they expected prices to drop this year.)

The only clear leader in the machine vision business, the report notes, is the highly specialized KLA (dedicated only to reticle and mask inspection). Automatix and View Engineering were named by the respondents as making the end users' short lists most often, as being the most likely principal vendors, and as having the most advanced support/service and the most advanced vision technology.

A new research report from International Resource Development, Inc. (IRD) also finds the vision systems industry overcrowded, with some 15 companies in the serious contender category. But IRD foresees three firms—GE, GM, and IBM—as likely buyers or crushers of the specialist suppliers.

IRD predicts that over the next 10 years, U.S. industry will buy a quarter of a million robots and that 60,000 of them will have vision capabilities. The prices, currently averaging around \$150,000, will fall rapidly. Buyer resistance, however, is anticipated because of reliability problems and design bugs of the new machinery. Only around \$20 million worth of robots was actually accepted and signed off for by their purchasers last year, according to IRD survey manager Matthijs Moes. He believes another \$15 million worth could have been shipped, but the machines are still waiting to be debugged and

put to work by the buyers. Such delays, Moes says, could prove the death of some smaller suppliers.

Contradicting other findings of only a year or two ago, IRD believes U.S. vendors will not be displaced by technology from Japan. “Advances in U.S. signal processing technology, derived in part from military-supported R&D and the VHSIC program, seem likely to keep the U.S. out ahead for some time,” Moes says. What might happen is a trickle-out, trickle-in arrangement between the two countries, with the U.S. letting go of some of its vision technology in exchange for Japanese hydraulics and precision engineering.

Addressing the issue of robot safety, Moes anticipates the new look in factory uniforms as pinstripes arranged in bar code language that spells out “Stop: A human is around.”

Although flexible manufacturing will improve U.S. industrial productivity over the next decade, such systems will not become widespread, according to a report from the Yankee Group. The Boston-based research organization foresees that only a few hundred FMSs will be installed by 1990. Where FMS installation does take place, it will come as a progression from numerically controlled machine tools through several intermediate stages, such as flexible manufacturing cells, to entire systems. But not all manufacturers will install the complete works, the study says.

Yankee's manufacturing automation planning service estimates that the FMS and flexible manufacturing cell market was \$262 million in 1984 and that it will rise to \$1.8 billion in

1994 1992
1989 1993 1990
1988 1997 1991
1986 1987 1999
1998

In The Robotics Age

1990. A survey of FMS end users in the U.S. indicated that 56 percent of the systems were used for manufacturing machinery and 41 percent for manufacturing transportation components in 1984. In six years, Yankee expects the construction and materials-handling industries to account for 12 percent of the market.

A report from the Sperry Corp. features optimistic news of an across-the-board increase in productivity, said to be the result of an expanded use of computers and factory automation. Joseph J. Kroger, president of Sperry's information systems group, points to the 14.7 million personal home computers and business workstations purchased in 1984 alone and to the 200 companies experimenting with "telecommuting," which allows workers to choose their hours and work environments, with a resultant upgrading of production. Annual sales of office automation equipment totaled approximately \$22 billion last year and are expected to rise to \$70 billion by 1988 and to \$124 billion by 1994.

Aging factories have enjoyed the benefits of computers, too—Kroger views computers and automation as their saviors. Products will be better designed and built, the report predicts, and the upshot will be lower prices for consumers and greater safety for workers.

Citing a report from the U.S. Office of Technology Assessment, Kroger concludes that computer-based automation will not bring about massive unemployment. There will be a shift in the sort of jobs available, away from blue collar positions and toward computer scientists and servicers. With the coming of age of the baby boom gen-

eration, the labor supply will be expanding by only 0.9 percent by 1990, and an actual labor shortage is possible.

The Robotic Industries Association (RIA) has developed a questionnaire intended to assess both short- and long-term robotic standards needs. The inquiry is being sent to robot users, builders, educators, accessory suppliers, researchers, government agencies, and unions to gather information that will allow the RIA to establish priorities in its standards development work. According to Samuel B. Korin, head of RIA's standards committee, the association is pursuing a democratic process in developing standards. The RIA's robot safety subcommittee has already developed a proposed American national standard that has met with positive response both here and abroad.

Artificial intelligence applications in manufacturing will be the subject of an international study to be conducted by Battelle Memorial Institute's Columbus Division and Geneva Research Center. Three areas of AI will be examined: expert systems, natural language interfaces, and vision systems. For each area, Battelle will gather and evaluate information regarding evolution, development, and availability from now until 1990.

The study team will also compile an inventory of hardware and software that will be commercially available for AI programming. With this information, Battelle will identify present and potential AI applications in manufacturing, determine hardware and software requirements for these applications, and forecast trends that will influence their implementation.

EDUCATION

The mechanical engineering department of **Penn State University** has become the first in the country to have an undergraduate and graduate vision laboratory. Dr. James Wamhold, professor of mechanical engineering, said the new lab would be devoted to true real-time product inspection. This approach, he said, would be in contrast to computer engineering programs at other universities in which computer use is directed toward analysis and simulation.

The new facilities will be constructed as part of major renovations planned for the mechanical engineering building, a project funded in part by a \$100,000 grant from the **Continental Group, Inc.** of Stamford, CT. The computer vision and inspection lab will be equipped with compatible vision modules, ultrasonic inspection and gauging modules, microcomputers, a signal laser, supporting hardware, and a workstation.

CORPORATE NEWS

► **Data General** has announced its support of two industry-standard communications protocols and has made a commitment to support the General Motors Manufacturing Automation Protocol for factory automation. In offering support for the Transmission Control Protocol/Internet Protocol (TCP/IP), the company becomes the first vendor to support this industry-standard network protocol for a native UNIX (DG/UX) and a proprietary operating system (APS/VS). Data General has also promised support for the Xerox Network System internet transport protocol under Data General's AOS/VS proprietary operating system.

► **Robotic Vision Systems, Inc.** has received two contracts from **General Motors Corp.** for robotic sealant systems. The \$6 million awards represent the first turnkey automation systems contracts the company has received from GM. Robotic Vision Systems is principally engaged in developing and manu-

facturing three-dimensional sensor-based intelligent robotic and inspection systems for industrial and military uses.

► **Laboratory Microsystems, Inc.** has set up a free computer bulletin board technical support service for registered users of its Forth development systems. The company promises to answer questions, suggestions, and bug reports left on the bulletin board within 48 hours. The board is available weekdays from 5 PM to 9 AM PST and around the clock on weekends and holidays. Both 300 and 1200 baud are supported. The board telephone number is (213) 306-3530.

PEOPLE

► **ASEA Robotics, Inc.** has named **Lance Hinatsu** director of its Troy, MI robotics center. He will be in charge of marketing, sales, applications engineering, service, and training for robotics customers in the automotive industry.

SCIENCE & TECHNOLOGY

Researchers at the **National Bureau of Standards (NBS)** are studying a new, automated laser-interferometer tracking system they hope will lay the groundwork for improved measurement of industrial robotic performance and aid in establishing industry standards.

The research prototype developed by the NBS metrology group consists of a single laser interferometer, a servocontrolled tracking mirror, a similar target mirror mounted on the robot's wrist, and a computer to control the system. Continuous measurements of the target mirror are made in real time while the robot is working at its normal pace. Position measurements include the three spatial dimensions and the robot wrist's roll and pitch.

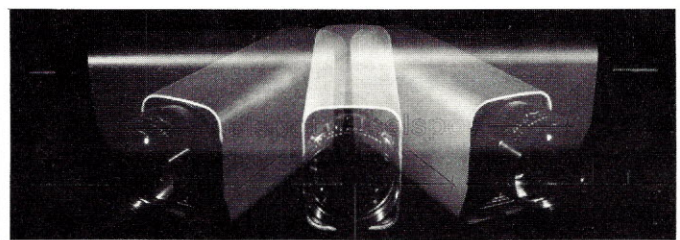
The full system will include precision transducers to measure the angular rotation of the mirrors and a standard laser interferometer to measure the path length of the beam. NBS researchers say the finished device should be capable of measuring the position of an industrial robot arm, in motion, to an accuracy of 12 micrometers (0.0005 in.) over the volume of a 3-meter (9.8 ft.) cube, an accuracy of about one part in 200,000.

Kam Lau of the NBS Center for Manufacturing Engineering says that robot manufacturers' quoted figures for the accuracy and repeatability of their robot arms are not entirely reliable, because factors such as the speed of a robot arm are not tested by the static measurements currently in use. Applications for the new measurement technology are expected to include assessing the accuracy of

milling machines, lathes, and coordinate measuring machines.

Another approach to robotic evaluation is being marketed by **Selspine**, a joint venture company of **Selective Electronic, Inc.** (Selcom) of Valdese, NC and **Spine AB** of Sweden. The Selspot II noncontact motion analysis system is intended to diagnose and, in some cases, to prevent certain problems:

- Robots do not always follow their programmed paths.
- The level of repeatability varies with the direction from which the robot arm is approaching a given spot.
- Poor acceleration/deceleration curves cause inefficient use of operational time.
- Motion drift makes daily reprogramming necessary to put the robot back in tune.
- Robotic interchangeability



is not perfect—one robot is not identical in performance to the robot it is replacing.

The Selspot II consists of four basic components: camera, light-emitting diodes (LEDs), LED control unit, and a main processing unit or controller. The LEDs are attached to selected points on the robot being monitored. Minute changes in position are transmitted by infrared beams through an optoelectronic detector. This component senses the center of the light image and generates output signals that are then converted into precise position in-

formation and routed to the controller unit. The controller converts the positions into digital or analog output data for real-time recording and analysis. Measurements are made in three dimensions.

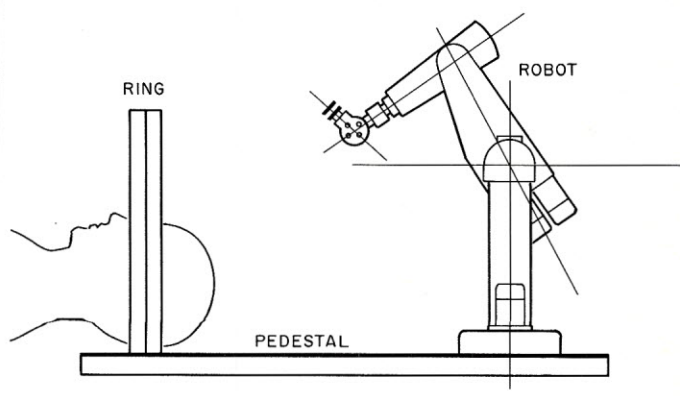
In addition to robotic evaluation, Selspot II has found applications in vibration analysis, measurement of shear and extension strain on polymeric materials, vehicle impact testing, deformation measurement, and human body studies such as the analysis of correct work positions, optimum work loads, and proper body movements.

ROBOT-AIDED BRAIN SURGERY

Robotics and medicine formed a successful partnership when a California neurosurgeon called in a robot as his assistant. The procedure they performed was the first operating-room use of a system designed to bring a new order of precision to the delicate work of brain surgery and diagnostics. An article in this issue by Dr. Y.S. Kwoh, "A New Computerized Tomographic-Aided Robotic Stereotaxis System," describes the system's design and construction. (The diagram at right, which appears in the article as a photograph, features the robot as it receives positioning commands from a computer.)

A spokesman at Memorial Medical Center, Long Beach, California, where Kwoh's research was conducted, said the operation was a needle biopsy on a 52-year-old man with multiple brain tumors. The

new procedure was explained to the patient, who was described as having "no qualms," but who did request anonymity. He was conscious throughout the operation and left the hospital three days later.



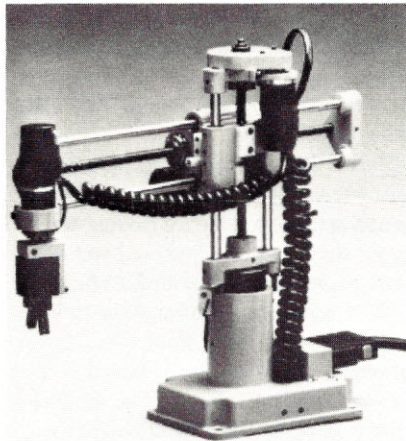
New Products

Cylindrical DC Assembly Servorobot

Advanced Technical Products has added a new cylindrical DC servorobot, the Model 88-4H, to its line. The company says the new robot offers small parts handling previously found only in far more costly equipment. It was designed for applications requiring precise horizontal and/or vertical linear motions and for multicompartment palletizing operations.

The 88-4H measures 16 in. high by 5 in. wide by 18 in. long and weighs less than 15 pounds. It has four DC servos with digital optical encoders. Ballscrew transmissions provide movements along two of the four axes with speeds up to 16 in. per second and with repeat positional accuracy to ± 0.004 inches.

Among other features are a six-program storage capacity, RS-232 interface, and a sequencer interface for I/Os. A palletizing teach box requiring only 3-point program-



ming for large matrices is one of several options.

For more information, contact: Samuel G. Manfer, President, Advanced Technical Products, Inc., 955 West River Parkway, Grand Island, NY 14072, telephone (716) 773-0972. Circle 50

Z80-Based I/O System

The new Arcus high-speed Z80-based analog and digital data acquisition and control system from Power Solutions features an on-board 823A arithmetic processing unit, a Z80 CPU, and three discrete buffered 12-bit analog inputs that provide 30 μ s conversion. The Arcus also has four programmable counter/timer channels, five byte-wide parallel I/O ports, two SPDT relays, and two buffered RS-232 serial ports. On-board memory includes 56 K by 8-bit RAM, ROM, or EPROM, plus 2 K by 8-bit EEPROM.

The system provides high-level floating-point arithmetic capability for complex algorithms and engineering formulas and supports a variety of peripherals.

For more information, contact: Power Solutions, Inc., 25 Main St., PO Box 878, Kennebunk, ME 04043, telephone (207) 985-2926. Circle 52

LISP for the Macintosh

ExperTelligence has begun delivery of a LISP development environment for the Macintosh. ExperLisp will be available as a complete workstation or as a stand-alone software package. According to the company, ExperLisp is a complete implementation of the LISP programming language and contains all the features of LISP dialects usually available only on much larger machines. It provides access to the Macintosh "toolbox," compiles directly to MC68000 machine code, and has 3-D and spherical graphics capability.

The ExperLisp workstation includes ExperLisp, a Macintosh XL with up to 4 megabytes of memory and a 10-megabyte hard-disk drive. The stand-alone software package requires a Macintosh with 512 Kbytes and an external disk drive.

For more information, contact: Clint Laskowski, Product Sales Manager, ExperTelligence, 559 San Ysidro Rd., Santa Barbara, CA 93108, telephone (805) 969-7874. Circle 51

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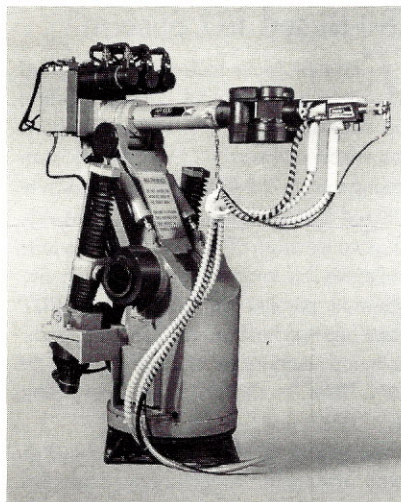
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New Products



Thermal Spraying and Grit Blasting Arm Robot

A computer-controlled, six-axis articulated arm robot specifically designed for thermal spray coating and/or grit blasting operations has been developed by Metco, Inc. The six axes of movement simulate the waist, shoulder, arm, and wrist of the human body; they can be controlled and manipulated individually or simultaneously, allowing the robot to maintain an accurate spray over flat, curved, cylindrical, or complex work surfaces. An acceleration or deceleration time of 350 ms allows very rapid direc-

tional changes. All process operations, including startup, part preheating, coating application, and shutdown, can be coordinated using the AR 1000 and Metco's Type 4HL tilting turntable unit.

The AR 1000 robot consists of six major components: the robot body, controller, operating module, interface module, teaching pendant, and CRT/keyboard unit. Programs are stored in the controller, which has 128K of memory and can handle up to 1000 point locations in space. Point-to-point programming is carried out by means of the teaching pendant, while off-line programming is done on the CRT/keyboard using high-level, motion-descriptive language. Up to 40 programs can be stored in permanent memory, and additional programs can be held in an optional magnetic tape cassette unit.

All power for the robot body flows through the controller. Circuitry includes controllers for the six DC motors on the body, 32 input and 32 output connectors for addition of auxiliary equipment, and circuitry that compensates for transients in line voltage. A separate fault-finding circuit displays any operational problems in English on the CRT screen.

For more information, contact: Jim Morris, Metco, Inc., Dept. 203A, 1101 Prospect Ave., Westbury, NY 11590, telephone (516) 334-1300.

Circle 53

Air Film Supported AGV

A new automated guided vehicle system designed to transport 10- to 50-ton loads has been introduced by Aero-Go, Inc. for moving heavy stock and production parts in computerized and robotic operations. Travel speeds are from 45 to 90 fpm.

The vehicle, said to have the highest capacity in the industry, rides on a paper-thin film of air created by four slide-mounted air bearings that eliminate floor damage. The inflatable air bearings are supplied with shop air from an umbilical hose on the vehicle's powered level wind/unwind reel. Two powered drive/brake system wheels are under the vehicle; emergency stop actuator bumpers are at each end.

Directional control is provided by a guide wire in the floor. Location is determined by radio signal. An on-board microprocessor interprets instructions, monitors sensor in-

puts, and can pass information to a system computer. It can also issue functional commands to ensure operational and program compliance.

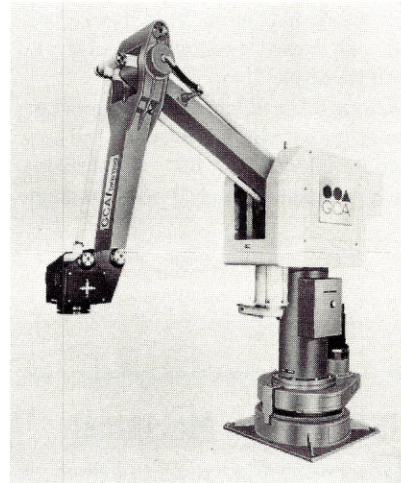
For maintenance, the vehicle can be operated manually and driven in areas without guide wires. Decks equipped with hydraulic arms or other systems for self-loading, unloading, and other automatic load-handling operations are optional. Safety is provided by the vehicle's constant monitoring of input information, hazard sensors, manual stop buttons, and interlocks for mechanical, hydraulic, pneumatic, and electrical operations.

For more information, contact: Aero-Go, Inc., 1170 Andover Park West, Seattle, WA 98188, telephone (206) 575-3344.

Circle 54

Heavy-Duty Industrial Robot

The new GCA/DK™ B3200 robot from GCA is designed for heavy-duty tasks such as material handling, loading and unloading pallets, and long-reach spot welding. The robot's end-of-arm capacity is 220 lbs., its reach is over 9 ft., and its work envelope about 650 cubic feet. All-electric DC servodrives on all axes and an automatic pneumatic counterbalancing system on the arm articulation are said to ensure rapid, smooth, responsive manipulation of maximum payloads at maximum speeds everywhere in the work envelope.



Four degrees of motion are standard: horizontal and vertical travel, horizontal sweep, and wrist yaw. Wrist pitch and wrist roll are optional. The robot uses a dual-coordinate system (cylindrical and Cartesian) to maximize dexterity. It is offered standard with the F200 controller for point-to-point applications or with the new CIMROC® 2 controller when either six-axis, simultaneous continuous path, or similar integration is required.

The externally mounted theta-axis motor is said to facilitate maintenance because it can be changed without suspending the robot body. A variety of optional accessories is available, including mechanical gripper hands, vacuum cup and magnetic lifters, fork lifts, and welding systems.

For more information, contact: GCA/Industrial Systems Group, One Energy Center, Naperville, IL 60566, telephone (312) 369-2110.

Circle 55

New Products

Solid-State CID Camera

A new charge induction device camera has been developed by General Electric for medical, industrial, and scientific applications requiring high contrast. The TN2509 monochrome camera has an imager made up of 28 micrometer square, contiguous pixels in a 256x256 array. A notched row electrode design provides a quieter, more uniform background image than has previously been available, the company says.

The camera measures 3 in. by 3 in. by 2½ in. and weighs less than one pound. An internal power supply permits regulation when operating from a 12 to 35 VDC source. Separate miniature adapters allow operation from a 120 VAC, 60/50 Hz or 220 VAC, 50 Hz source. The camera employs LSI circuitry with limited discrete parts.



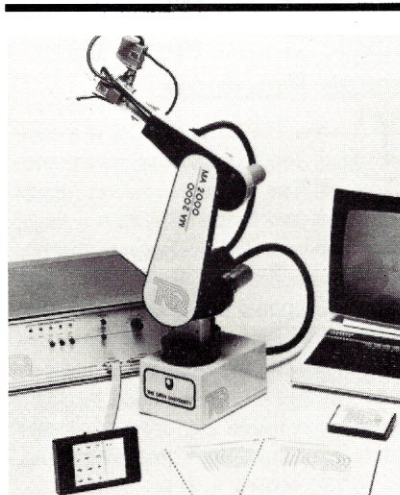
Synchronization of the TN2509 is with 5 V transistor-transistor logic level, 75-ohm impedance signals consisting of H reset, V reset, and 14.318 MHz or 10 MHz clock. Inject/Inhibit is also included for stop action or image integration. The source of these signals may be several hundred feet away.

For more information, contact: Fred Sachs, Electronic Camera Operation, General Electric Co., 890 Seventh North St., Liverpool, NY 13088, telephone (315) 456-2832.

Circle 56

Literature and Brochures

Over 890 subfractional horsepower motors and other motion-control products manufactured and marketed by Stock Drive Products are featured in a new free 130-page catalog, SDP-823. The devices are listed by category: STD-BUS motor controller cards, stepper motors, optical en-



Six-Axis Miniature Robot with Teaching Applications

A British-made robot originally designed for use at a university is said to provide all the features of current technology industrial robots. The MA2000 from TecQuipment has powered joints with feedback control and specifications unusually comprehensive for educational robots, the company says. It has a powered gripper, a 20 in. reach, a 2.2 lb. deadlift capacity, and a repeatability of 0.08 in.

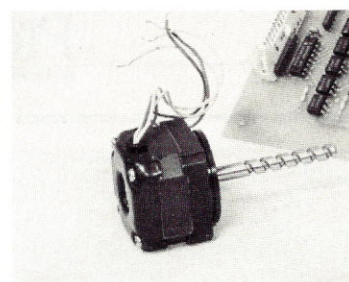
Software permits interfacing with a variety of computers. The MA2000 can be programmed by several methods, including a "lead-by-nose" method for both continuous path and point-to-point operation. It can also be programmed for point-to-point operation by off-line computer or by touch keypad. Safety features include an emergency stop button and automatic braking on the three axes in case of a power failure.

For more information, contact: Andrew Spencer, President, TecQuipment, PO Box 1074, Acton, MA 01720, telephone (617) 263-1767.

Circle 57

coders, DC motors, tachometers, DC gear motors, synchronous motors, AC gear motors, reduction gearboxes, speed reducers, and gearheads. Product applications include robotics, computer peripherals, and instrumentation. Contact: Herb Arum, Stock Drive Products, 2101 Jericho Tpk., New Hyde Park, NY 11040, telephone (516) 328-0200.

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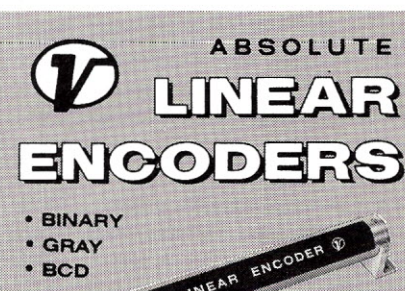
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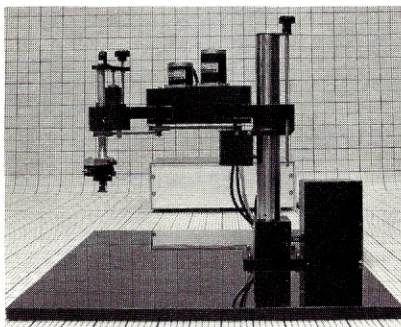
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Circle 36

New Products



Articulated Robot for Education and Light Industry

The Capek I from FMS International is designed both for teaching and assembly operations. The robot is 10 in. tall and weighs 50 lbs. Its maximum load, including the end effector, is 4.5 lbs. There are four programmable axes of motion: shoulder, 200 degrees; elbow, 180 degrees; vertical, 2 in.; and rotation of effector, 360 degrees. Repeatability is given as 0.01 in.

The robot is driven by DC stepper motors and pneumatic axes. Programming is carried out by teach mode, point-to-point, or time delay linear interpolation, and Capek is described as easily interfaced to microcomputers.

For more information, contact: FMS International, Inc., PO Box 8727, Coral Springs, FL 33075, telephone (305) 752-0661. Circle 59

Communication Rangefinder for Remote Sensing

Interface Technology is offering a new product in its line of smart sensors for robotic and industrial control applications. The unit uses the Polaroid ultrasonic rangefinder module, coupled with a single chip microcomputer and RS-232 interface to provide a computer-compatible readout of distance and/or velocity. The range is 35 ft. in air with accuracy said to be a small fraction of an inch.

The unit can be configured to read out continuously, on demand, or when a limit is exceeded. Readings are selectable in English or metric units. The interface communicates at RS-232 levels at 1200 baud. Optional temperature correction can be ap-

Single Board Multibus Image Processor

The new MATROX MIP-512 is a complete image-processing system providing real-time image acquisition, image processing, and image display on a single multibus board. VLSI technology provides real-time digitization, true DMA, data storage, a sophisticated ALU, and a 16.7 million color palette at a fraction of the cost of earlier systems, according to the manufacturer. The MIP-512 is intended for high-performance image capture and display systems used in robotics, medical imaging, and remote sensing systems.

The system's 256 bytes of on-board memory provide 512×512 pixel resolution with 256 colors or intensities per pixel. True DMA allows images to be digitized and displayed in real time with transparent access to the video RAM by the host processor. All computations are performed in real time without intervention from the host processor. Multiple boards can be combined to increase the precision of the calculations from 8 bits to 16 or 24 bits.

For more information, contact: Ed Dwyer, Sales Manager, Matrox Electronic Systems Ltd., 1055 St. Regis Blvd., Dorval, Quebec, Canada H9P 2T4, telephone (514) 685-2630. Circle 60

plied to the readings. The circuitry is designed for low power consumption, and power can be supplied over unused pins of the RS-232 cable.

The rangefinder is expected to find industrial applications, where the presence of people or objects must be monitored remotely. The unit is also available without the rangefinder front end and can be expanded with digital or analog inputs for remote data collection from a variety of sensors.

For more information, contact: Patrick H. Stakem, Interface Technology, Inc., PO Box 3040, Laurel, MD 20708, telephone (301) 490-3608. Circle 61

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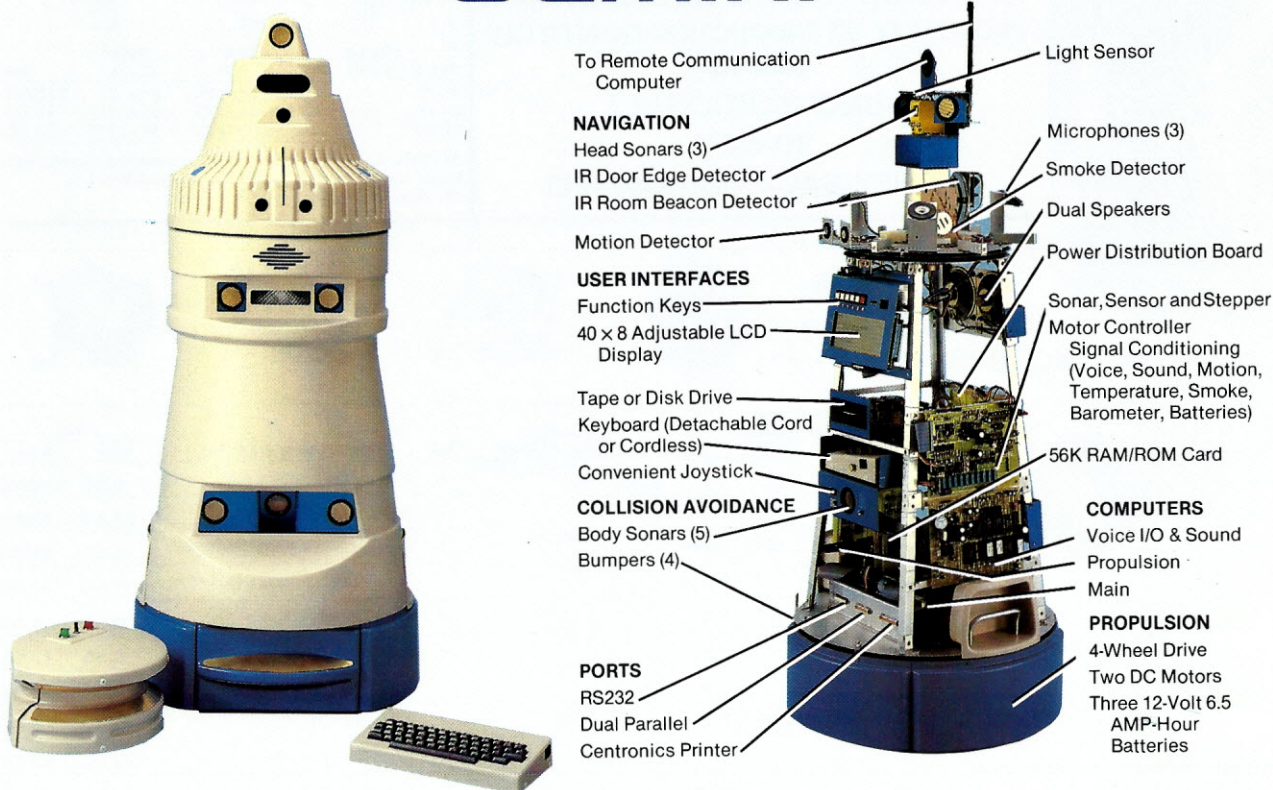
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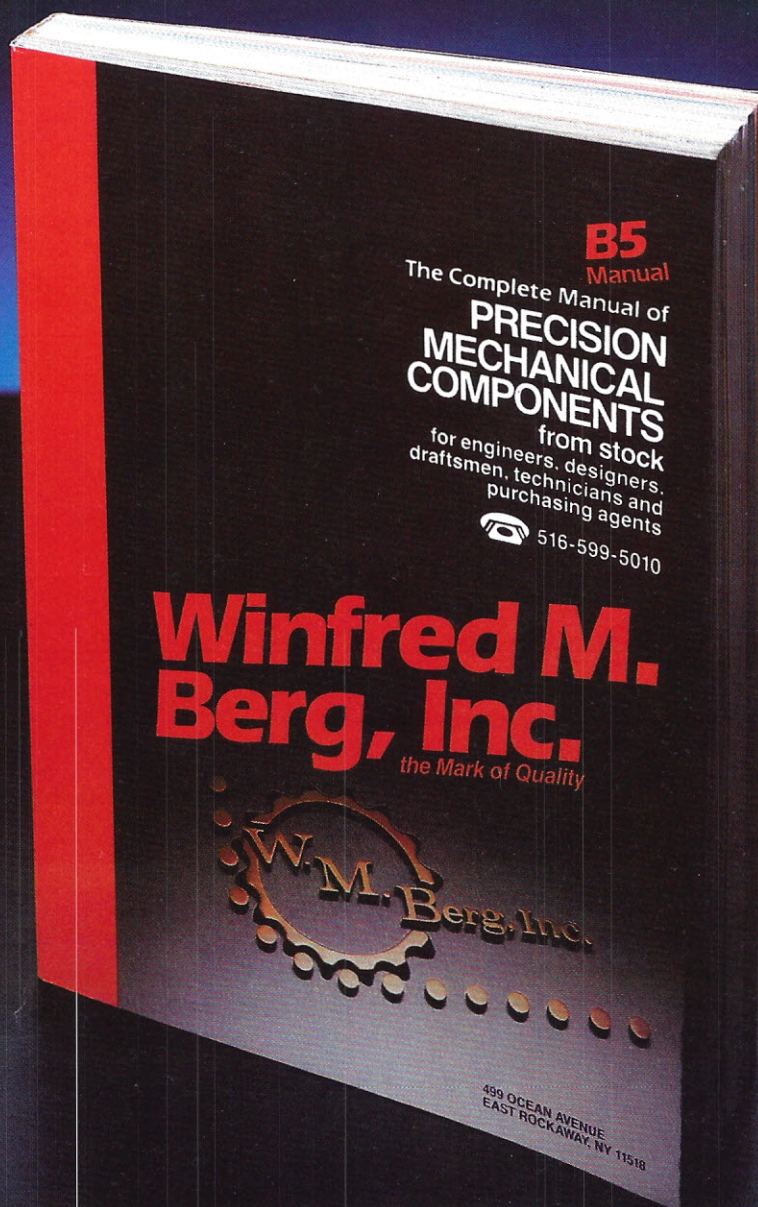
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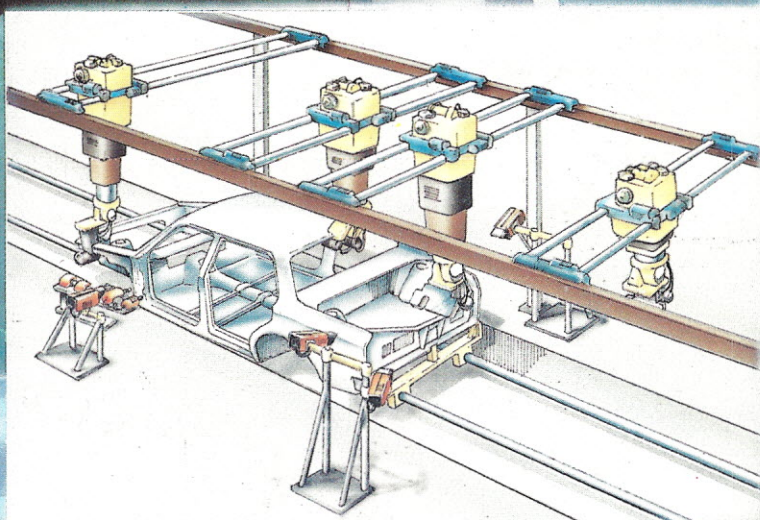
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